NORWEGIAN SCHOOL OF SPORT SCIENCES

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«Comparing the effects of different variants of the free weight barbell squat to machine-based squatting exercises. A systematic litterature review»

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Abstract

The purpose of this review is to compare the effect of different free weight and machine variants for the squat exercise.
The different variants are presented with factors that may influence the effect of each exercise.
A systematical review of relevant articles is performed, with emphasis on 3 outcomes: Muscle strength, hypertrophy and athletic performance. All studies are presented in a table. There where some difficulties in finding hypertrophy studies on single exercises, therefore only 9 studies are included, compared to 14 for strength and 21 athletic performance. These findings suggests that squat is superiour to leg press when increasing athletic performance, but there are no significant differences between free weight and machine squats. Individuals can lift heavier loads with the use of machine and improve 1RM faster. Altough the strength gains on machines, are not as transferable to other exercises and athletic movements as free weights. There is not suffisient evidence to conclude weather free weights or machine induces more hypertrophy.

Content

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«Comparing the effects of different variants of the free weight barbell squat to machine-based squatting exercises. A systematic litterature review»

1. Introduction

The majority of national health organizations reccomend resistance training (RT) for fitness programs containing aerobic and flexibility exercises (Kraemer, Ratamess and French, 2002) RT has numerous of well documented health benefits such as: reduced body fat, increase metabolic rate and decrease blood pressure. The cardiovascular demands of resistance exercises can improve blood lipid profiles, glucose tolerance and insulin sensivity. It also increases the cross sectional area of the muscle and connective tissue as well as daily functional capacity (Kraemer et.al, 2002) Improved strength, power, muscular endurance and hypertrophy leads to enhanced athletic performance and improves daily function in the elderly (Staron et.al,1994)

Arguably the most popular way of performing RT is by the use of free weights, as this has long been a standard way of measuring strength (Lennon, Mathis & Ratermann, 2010) With the use of free weights (FW) the performer must apply adequate force and control the weight through a full range of motion (ROM) While the weight is lifted, both prime movers and synergists are activated (Schwanbeck, Chilibeck & Binsted, 2009)

Weighted machines is another approach to RT where the movement is guided through a fixed ROM (Lennon et.al, 2010) . There are different opinions concerning the two variants, but subjective opinions are far more common than scientific evidence (Haff et.al, 2000) Results are various where studies report more weight being lifted by the use of machines (Scwanbeck et.al,2009) but also also free weights (Pimental et.al, 2016) with the choice of exercise and design of machines playing an important role (Cotterman, Darby & Skelly, 2005)

According to Haff et.al, 2000 (roundtable discussion of sport scientists) there are several possible advantages and disadvantages for both free weights and machines. As machines are typically less intimidating, easier to use, and may have a lower risk of injury, free weights may be more relevant to daily life movements, and activate more muscle mass. It also allows for more variants of the

exercise (e.g front squat)
If these allegations are right, there is reason to belive that individuals managing the free weight variants will further improve athletic performance as it activates more muscles mass wich may alter force production and has a movement pattern more similar to athletic movements e.g jumping. We could also think that individuals may increase the load on machines more quickly as they are not required to spend time learning the exercise techniqually. It will be interesting to see weather machines or free weights are more efficient for gaining muscle mass. The techniqual advantages of the machine may bridge the gap between the higher muscle activity of the free weights if the same relative load is applied.
The main reason for chosing the squat exercise is that it activates some of the largest, most powerfull muscles of the body, (Escamilia et.al, 2001) It is by many considered the best exercise for strengthening the muscles around the knee and hip joint (Escamilia et.al, 1998) Lower extremity strength is a major predictor for independence and function for elders and "airsquats"(no weight) is used as a screening tool physical function (Chandler et.al, 1998) The barbell squat may also alter sports performance through strengthening the muscles that produce force during athletic movements such as running and jumping (Crewther et.al, 2011)
Tough there is plenty of positive evidence for RT, this review will try to assess if free weight or machine variants of the squat exercise is more efficient, having in mind that there may be differencies among populations. From previous EMG studies, it is suggested that free weights can generate higher muscle activity than machines (McCaw & Friday, 1994, Escamillia et.al, 2001) But reportedly free weights counts for 90% of acute injuries (Gray & Finch, 2015)
The purpose of this study is therefore to review the different benefits of machine and free weight variants of the squat exercise, with the main focus on 3 outcomes: Hypertrophy, Strength and athletic performance. And to explore weather there are differencies/similarities between the variants and outcomes.

2. Theory

The majority of national health organizations reccomend resistance training (RT) for fitness programs containing aerobic and flexibility exercises (Kraemer, Ratamess and French, 2002) RT has numerous of well documented health benefits wich this following chapter will systematically present both physiological and psychological.

2.1. Adaptations to RT

Three principples are seen as mandatory for optimal effect of RT (Kraemer et.al, 2002)
progressive overload is the progression of gradualy increased loads during RT, As the athlete gets stronger, further progression is only achieved by forcing the human body to meet higher physiological demands. In preventing injuries and obtaining long-term health improvements, the importance of gradualy increasing the load is essential.
Specificity refers to our bodys ability to adapt to the program variables. These adaptations are specific to the demand placed upon the muscle. For example, high velocity of movement is required for achieving explosive strength gains (Newton & Kraemer, 1994) Intensity and volume are important adaptations in RT. Intensity refers to the frequency and the physical effort in training sessions, while volume is the total amount of weight lifted, multiple with repetitions (100kg x 10 = 1000kg volume) *Variation* is the third principple that can maximize the effect of RT, it is defined as "the systematic change RT regime over time, wich allows the training stimulus to remain optimal" for example, periodized training with emphasis on variation has proved to be more effective in increasing 1 RM of the barbell squat (Stone, Potteiger, and Pierce, 2000)

2.2. Muscular strength

It is no secret that muscular strength increases through systematic RT. Tough the level of improvements variates across populations (ACSM, 2002) . In a review of more than 100 studies on different levels of RT, the ACSM reports that for training interventions lasting 4 weeks to 2 years, the average muscular strength increase was 40% in untrained, 20% in moderately trained, 16% in

trained, 10% in advanced and 2% for elite practicioners. There are mainly 3 pathways to increased muscular strength: *Neural adaptations* an increase in muscular strength without increasing the cross-sectional area (CSA) is achieved through neural adaptations, wich is primarly expressed in the early phases of RT (Gabriel, Kamen & Frost, 2006) It is associated with the subjects ability to increase the amplitude of surface electromyography (SEMG), wich means greater activity of the muscle (Gabriel et.al, 2006) This involves a increase in neural drive that improves the output of the CNS to activate more muscle fibres (Gabriel et.al, 2006) The underlyimg mechanisms for this altered muscle activity are changes in the patterns of motor unit firing and the altered firing rate wich occurs during muscular contraction (Gabriel et.al, 2006). *Cross sectional area (CSA)* Is the maximal number of acto-myosin crossbridges that can be paralelly activated during a contraction of the muscle (Rutherford & Jones, 1992) The maximal capacity of a muscle to generate force, is propotional to its physiological CSA (Rutherford & Jones, 1992) several studies report a strong relationship between muscle, the CSA and muscle strength (Ikai & Fukunaga, 1968, Maughan, Watson & Weir, 1983, Young et.al, 1984, Seymour et.al, 2009) Also strong correlation between muscle torque and CSA wich alters force production (Schantz et.al, 1983)
Changes in muscle architecture and pennation angle Maximal muscle force is expected to increase when the changes of the muscle fibre pennation angle, rises to its upper limits of 45 degrees. In addition, regulary pennated muscles are capable of generating more force than than non-pennated muscles (Rutherford & Jones, 1992) Several studies report a increased muscle fibre pennation angle together with strength gains following systematic RT (Rutherford & Jones, 1992, Aagaard et.al, 2004, Kawakami et.al, 1993)
Furthermore, improving muscular strength has several benefits, such as enhanced ability to sit/stand, prevent falls, increase walking speed in middle aged subjects (Weiss et.al, 2000) it also enhanced the fitness for recreationally trained individuals and athletic performance at all ages and levels (Kraemer & Ratamess, 2000)

2.3. Hypertrophy

There is no secret that regular RT induces muscle hypertrophy (Schoenfeld, 2010). There are several benefits from increasing the size of a muscle: First of all, a larger muscle has the capability to produce higher force wich leads to improved athletic performances. It has a positive effect on the process of aging, sarcopenia and it increaseses the lean body mass (Johnston, DeLiso and Parise, 2007). The gains of force and power as a result of muscle hypertrophy creates biomechanical advantages in activities and sports that involve throwing, running, jumping and bodily contact

(Biolo et.al, 1997).

Muscle hypertrophy is defined as the "enlargment of muscle cells"(Braun, Anderson & Miller, 2006) It is achieved by an increased protein metabolism, as the rate of protein synthesis is altered . It depends on chained amino acids to bind proteins (Biolo et.al, 1997). Muscle hypertrophy is more expressed in fast twitch muscle fibres (Biolo et.al, 1997) Single bouts of exercise are suffisient to alter the protein synthesis. It is increased 2-3 hours post exercise, before it peaks about 24 hours post exercise (Biolo et.al, 1997) Another pathway to muscle hypertrophy is the damage of muscle through mechanical actions or metabolic stress, wich primarly occures with chronic RT (Schoenfeld, 2010). The remodeling of tissue post RT is affected by levels of testosterone, insulin and growth hormone levels, wich are all more expressed in strength trained athletes (Hakkinen et.al, 1987) Some studies detect "hyperplasia" wich is a increase in number of muscle cells (Antonio & Gonyea, 1993) tough there is doubt around this mechanism as it occurs in grown animals and perhaps in human athletes (Antonio & Gonyea, 1993) Muscle hypertrophy is the predominant factor for the increase of muscle size and exercise programs aiming to increase muscle usually prefers a moderate repetition range (6-12 repetitions) using moderate to heavy weights and performing multiple sets (Wolfe, LeMura, Cole, 2004)

2.4. Athletic performance/daily function:

RT can enhance athletic performance as it increases muscle size and strength wich alters force production. This is essential in sports involving running, throwing, jumping and bodily contact (Escamillia et.al, 2001) There is also evidence that RT has a positive influence on balance and motor control (Hrysomallis,2011)

Perhaps the most effeicient exercise is the back squat as it involves important coordination interaction of multiple muscle groups and strengthens the prime movers for the hip and knee joint, wich are needed to support explosive athletic movements such as running, jumping and lifting (Escamillia et.al, 2001) Several studies report positive effects on jumping/running as a result of chronic training (Baker, 1996, Marques, Gonzalez-Badillo & Jose, 2006) but also acute effects through implementing loaded barbell squat as a warm up routine (Crewther et.al, 2011) In addition, the "squat movement" translates to tasks of daily living such as sitting and lifting (Myer et.al, 2014) The unloaded barbell squat is widely used as a screening tool that can identify biomechanical deficits wich hinders optimal movement patterns wich may negatively affect physical performance and cause injury (Padua & Hirth, 2007)

Primarly the back squat is used for strength assessment but its also suitable for detecting neuromuscular control, stability and mobility issues (Escamillia et.al, 2001)

2.5. Muscle Power

The ability to develop muscle power is important both in sports and activities of daily living. Power production, refers to the muscles capability to produce more power over a shorter amount of time (Newton, Kreaemer, Hakkkinen, 1999) Many daily tasks requires some degree of power production such as hitting, kicking, carrying, running, lifting, throwing, jumping and climbing(Newton et.al, 1999). High force production at fast and slow velocities of muscle action is achieved by training the stretch-shortening cycle or improving coordination, movement patterns (Mina et.al, 2016) RT can also alter muscle power, especially with the use of variated resistance, such as chain or elastic band (Wallace et.al, 2006, Stevenson et.al, 2010, Mina et.al, 2016) The principple of "specifity" is important and in general it is recommended to combine traditional heavy RT with exercises performed at 30 to 60% with emphasis on high velocity of movement through a full ROM (Newton et.al, 1999)

2.6. Muscular endurance

Increased muscular endurance can improve the quality of life, and enhance tolerance to exercise (Taaffe et.al, 1999)

RT has the ability to increase absolute muscular endurance, wich is defined as "the maximum amount of repetitions performed at a specific load" (Marx et.al, 2001) But the influence of local muscular endurance (the ability of a muscle to sustain repeated contractions for an extended amount of time) is often limited (Mazzetti et.al, 2000) There is a relationship between improvements in muscular strength and muscular endurance but if a individual wants to improve their local muscular endurance, the principle of specificity is essential (Marx et.al, 2001)Lighter loads with many repetitions (20+) is recomended for local muscular endurance (Mazzetti et.al, 2000) The use of heavy loads (6-8RM) can also be effective, combined with short rest periods, wich will simultaneously alter muscular strength and hypertrophy, compared to lighter loads (Anderson & Kearney,1982)

2.7. *Flexibility*

A previous myth has been that the increase of muscle mass, would negatively affect flexibility, altough there is no evidence that suggest the verity of this alteration (Kraemer et.al, 2002) RT for 8 weeks alone, not combined with stretching exercises can improve flexebility by 12-15% in elderly individuals. The greatest results where observed in individuals with low flexibility scores (Barbosa et.al, 2002). It is important that the exercises is performed using full ROM, as it also may reduce the risk of injury. If RT and flexibility exercises are combined, resistance exercises should be performed first. According to Behm, Button & Butt, 2001, RT performed after 5-10 minutes of intensive stretching, lead to significantly lower force and power output during the RT, compared to when it was performed 5 to 10 post RT.

2.8. *Body composition*

Obesity is a cronic metabolic disorder, affecting large parts of the world. It is often associated with cardiovascular diseases, morbidity and mortality. There is clear evidence that patients suffering from coronary heart disease, diabetes 2, insulin resistance, stroke, colon cancer and hypertensions in frequently posesses a high fat percentage (FM) and body mass index (BMI) the mortality rate is 50-100% higher with a BMI of more than 30 (Williams, 2001). As for the effect of RT on obesity, studies has shown to decrease body fat percentage, as much as 9% (Kraemer et.al, 1997) Consistent RT over time, leads to more lean tissue mass, higher metabolic rates, and higher energy expenditure (EE) and trained individuals reportedly expend more energy during RT than untrained individuals (Poehlman et.al, 1992) RT is also an effective tool for the maintainance of fat free mass (FFM) and preserving a higher resting energy expenditure following weight loss (Hunter et.al, 2008)

2.9. *Blood pressure*

Elevated blood pressure is defined as a resting blood pressure value of more than 140/90 mm hg (Kelley & Kelley, 2000) Around 43 milions (43%) of the U.S adult population is affected (Kelley & Kelley, 2000) Several recent studies shows that RT can have a possitive effect on the blood pressure (Kelley and kelley, 2000, Taaffe et.al, 2007) Taffee et.al reported that 20 weeks of progressive RT reduced the systolic and diastolic blood pressure by 6 and 3 mm hg. These reductions are relatively small and some studies report that endurance training (ET) to be more effective (Cornelissen & Fagard, 2005, Fagard, 2006)

As for RT Cornelissen & Smart, 2013 found isometric RT to have the largest reduction on blood pressure (-10.9 mm hg) both ET and RT reduced systolic and diastolic blood pressure but a combination of RT and ET only reduced systolic blood pressure. Reduction of blood pressure through exercise seems greater in patients already suffering from hypertension (Cornelissen & Smart, 2013) The changes in blood pressure as a result of consistent RT is most likely a result of improved body composition such as decreased fat mass and body salt (Kraemer & Ratamess, 2000) More contribution from our muscles reduces cardiac demand during submaximal exercise (Kraemer & Ratamess, 2000)

2.10. Diabetes 2

Together with following a healthy diet, exercising plays an important role in managing the type 2 diabetes. The prevalence of diabetes 2 increases with age and is associated with reduced muscle mass, strength, and metabolic control (Dunstan et.al, 2002) As the patients suffering from diabetes 2 are typically obese, they may have a hard time performing a suffisient amount of aerobic activities, therefore RT should be considered in their training program (Eves & Plotnikoff 2006) RT improves the metabolic health by increased insulin sensivity and glycemic control (Hawley & Lessard 2004) the elevated demand in the muscles alters insulin transportation of glucose through the blood and to the muscles (Dela & Kjaer, 2006)

ASCM has involved RT in their perscription for diabetes 2 patients, they recommend 1 set of 10-15 repetitions and 8-10 exercises twice a week for beginners, then eventually progressing to 3 sets and 3 sessions per week (Albright et.al, 2000)

2.11. Cancer treatment

Androgen deprivation therapy (ADT) is used for managing prostate cancer and improves chances of survival in the early stages and to gains control of the disease in advanced situations (D'Amico et.al,2004) ADT is accompained by multiple side-effects such as decreased muscle strength, bone density, increased fat mass and risk of injuries (Sharifi, Gulley and Dahut, 2005)

RT has reported improvements in physical function and quality of daily life in prostate cancer patients (Segal et.al, 2003, Galvao et.al, 2006) Increased muscle strength has occured without negative effects on the disease control after 12 weeks of moderately intensive training (Segal et.al, 2003) and 20 weeks of heavy resistance training (Galvao et.al, 2006)

Breast cancer is the most comon type of cancer in women worldwide (Imaginis, 2007) some of the long-term side effects of treatment include, fatigue, depression, weakness, immune system dysfunction, loss of bone, upper body pain and decreased strength, flexibility and functioning (Hack et.al, 1999) According to a review of studies on Progressive RT in breast cancer patients, progressive RT obtains health and clinical benefits for women treated with breast cancer, emphasis should be on upper-body strength. Moderate intensity using standard equipment is recommended (Cheema et.al, 2008)

2.12. Bone Mass

Osteoporosis means "loss of bones" and is characterized by loss of bone mass and bone mineral density, wich increase the risk of fractures primarily in the hip, spine and wrist.(Layne & Nelson, 1999) It is a global phenomen, that affects more than 200 milion people worldwide (Galsworthy, 1994). The risk of osteoporosis is typically higher for females, approximately 80% of the 25 millions suffering from osteophorosis in the U.S are females (Galsworthy, 1994) Hip fractures from osteophorosis leads to 12-20% deceding shortly after due to complications of surgery (Glasworthy, 1994)

Weight-bearing activities such as RT increases the mechanical stimulus on the bone, and is important for maintainance and improvement of bone health and longevity. This can be achieved during multiple-joint structural exercises where an uneven strain is put upon the bone (e.g barbell squat) Influenced by the intensity of resistance, number of sets, rate of loading, direction of forces and frequency (Vincent & Braith, 2002) For improving bone mass, high intensity, training at 80% of 1RM for a period of 6 months significantly increased bone mass density of the femoral neck and bone turnover in elderly men and women (Vincent & Braith, 2002) It is recommended that multiple sets are performed with moderate to heavy loads and multiple-joint exercises for the effectiveness of bone loading (Kraemer et.al, 1997)

2.13. Sarcopenia & aging

Is a term for the loss of muscle mass and strength that occurs with aging (Doherty, 2003). Sarcopenia is considered a major factor for frailty and functional impairment at old age. Progressive wasting of muscle mass is a part of the ageing process (Doherty, 2003). It affects 8.8% of instituztionalized middle aged women and 17.5% old men (Morley et.al, 2001) The consequences of sarcopenia are far worse for obese individuals (Morley et.al, 2001) Aging negatively affects the fast-twitch (type IIa) muscle fibres (Deschenes, 2004). There is evidence for a decreased synthesis of myosin heavy chain proteins, wich are the major anabolic proteins and producers of anabolic hormones. This hampers the skeletal-muscle capacity to include amino acids and proteins for the protein synthesis (Deschenes, 2004) On the other hand, there is a increased release of catabolic agents that accelerates the loss of muscle mass (Deschenes, 2004) RT is highly reccomended for the elderly population as it attenautes the loss of muscle mass that accelerates at the age of 60 (Jespersen, Pedersen & Beyer, 2003)

The power production is reduced even more than strength, wich increases the risk of falling and injuries (Jespersen, Pedersen & Beyer, 2003) RT programs at medium-low intensity focusing on improving strength and power, performed 3 times per week has shown to significantly improve muscle strength and prevent the risk of falling in 60-80 year old sedentary subjects, wich improves the chances of longevity (Marini et.al, 2008) A structured program, targetting large muscle groups, with calculated series and repetitions with progressive loads for extended time periods are reccomended (Marini et.al, 2008).

2.14. Mental health benefits

Numerous of studies demonstrate that RT and physical activity has a positive effect on mental health outcomes. The vast majority of studies found are on either depression, anxiety or cognitive functions (Connor, Herrig and Caravalho, 2009)

Depression and anxiety: The positive results of RT on depression and anxiety are consistent, but the mechanisms remain unclear (Craft & Perna, 2004) Several hypothesis are made, but there are little evidence that either confirm or refuse these theories (Craft & Perna, 2004)

Thermogenic hypothesis: The elevated body temperature in specific brain regions following exercise is responsible for the mental well-being, feeling of relaxation and released muscular tension post exercise (DeVries, 1981)

Endorphin Hypothesis: Increased amounts of endorphins released post exercise has a positive relationship to enhanced mood and overall well-being (Johnsgard, 1989)

*Monoamine Hypothesis:*Exercise increases the aviability of neurotransmitters (e.g seretonin, dopamine) that dissapears during depression (Ebert & Goodwin, 1972)

*Distraction Hypothesis:*Exercise functions as a distractor from worries and depressive toughts (Leith, 1994)

Self-efficacy hypothesis: Exercises enhances self-efficacy, wich is the inner belief that one can

perform specific tasks, by possessing the required skills and produce desired outcomes (DeVries, 1981)
Probably there are multiple reasons and combinations for the mental health benefits, arising from RT (Connor et.al, 2009) social interactions wich typically occurs in exercise, but there is not suffisient amount of studies to distinguish the mechanisms behind the benefits for RT and ET (Connor et.al, 2009)
Cognitive functions: A complete understanding of the mechanism behind the positive effects of RT on mental health outcomes is yet to be achieved, but Dietrich 2004 suggests that “during exercise, the increased neural activation required to run motor patterns, assimilate sensory inputs and coordinate autonomic regulation, this results in a transient decrease of neural activity in the prefrontal cortex that are not performing during exercise, a exercise induced state of frontal hypofunction provides a coherent account of the influences on emotion and cognition"
RT significantly increased shifting ability and working memory, compared to balance and tone exercises in elderly women (Liu-Ambrose et.al, 2010) no significant differences in training 1 or 2 times per week, suggesting a low to moderate training volume for improving cognitive functions in elderly.

3. Free Weights

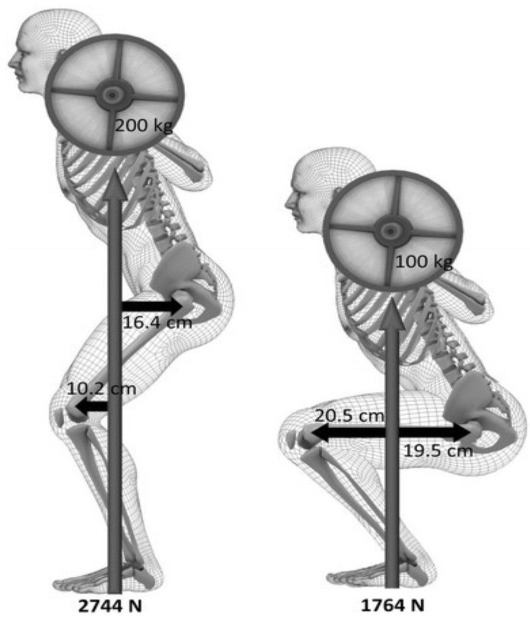
3.1. Barbell back squat

Is a dynamic exercise, widely regarded as a important part of RT programs, aiming to improve strength and power for sports such as football, track and field, powerlifting and olympic weightlifting (Escamillia et.al, 2001) the back squat first of all, strengthens the muscles surrounding the knee and hip joint as well as lower back. It is considered an important tool for enhancing athletic performance as it improves running speed and jumping ability and limits the risk of injury (Hodgson, Doherty & Robbins, 2005) The barbell squat is frequently used in knee injury rehabilitation such as post ACL reconstruction surgery (Lutz et.al, 1993)
When performing the barbell squat, the individual typically starts in a uppright position with full extension of the knees and hips. The barbell is positioned slightly above the trapezius muscles for highbar and on the lower part of the trapezius for lowbar (Glassbrook et.al, 2017) the subject then squats down in a continous motion (Escamillia et.al, 2001) For a valid squat in a powerlifting competition, the the top of the knee must be paralell to the top of the hip before starting the ascent .

The main muscles that are active during the squat are, the quadriceps, hamstrings, gluteus and trunk muscles. Muscle activity is primarly affected by the load, but different variants, stance width, depth and belt use, can also influence (Clarke, Lambert & Hunter, 2012)

3.2. Biomechanics

In performing a back squat, the gravity works on the bar and pulls the body down. At the same time, it is a opposite force, working uppwards from the surface, wich is sensed on the foot. In analyzing the barbell squat, it is recommended to use the force from the surface, because it is essential in performing exercises where the legs are splitted apart, such as squats, sumo deadlifts and lunges. The primary involved joints of a squat, is the knee and hip joint. (Muscle animations)
When forces are applied on the joints, the moment arm is decided. The moment arm is defined as the perpendicular distance from the force, to the joint. When the moment arm increases, the strain on the muscles acting across the joints increases. The moment arm increases with the depth of the squat and is at is greatest when the femur is paralell to the surface, wich explains why deep squats are more demanding. (Muscle animations)



(Blomqvist et.al, 2013)

The figure above shows the difference in momentarm of the knee and hip joint while performing shallow vs deep (paralell) squats. As we se, the momentarm is shorter for shallow squats, therefore the muscles on the front side of the thigh and buttocks are not generating as much force to move the weight, compared to paralell squats where the moment arm is longer.

3.3. Technical variations

There is several ways to perform a barbell squat. Some individuals perform the exercise with their back placed vertically, while others are more forward leant (Muscle animations). In a traditional squat, the moment arm of the knee and hip joint, is relatively similar while it is important to keep the center of gravity above the foot. If the center of gravity is placed in front of the foot, the subject will fall forward. Once the upper body is in a more uppright position, the knees are placed further forward than the foot. This means that the moment of the knee joint is large, and therefor a greater exterior force that the muscles must counteract. As the force vector works behind the knee joint, the muscles on the front side is activated (quadriceps) since the force vector works in front of the hip joint, the muscles on the back side is activated (gluteus maximus) When a subject leans forward, it increases the moment arm of the hip joint wich leads to higher activation of the hip extendors (gluteus maximus and hamstrings. The hamstrings are more activated when the subject is forward leant as it is more extended and further shortened. Shortening of a muscle is essential, for its contribution in the execution of a motion. In contrast, there is little change of length in a standard squat motion, where the hamstrings primarly works as stabilizors , and their overall contribution is minimal.(Muscle animations)

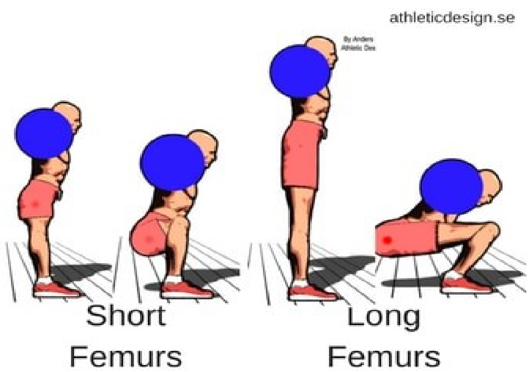
The same principle works for other exercises such as the leg press as seen in the figure, when the feets are placed higher on the platform, the momentarm of the hip joint increases wich alters the contribution of the gluteus muscles and the hamstrings. (Muscle animations)

3.4. Anthropometric differencies

The most significant anthropometric difference in performing a barbell squat, will be the length of the femur on the person squatting. Different techniques will be suitable for the person performing the squat, dependant on its body measurments.

For someone with long femurs, the hips will be pushed far back and the knees can still be in front of the toes. The shinbones will lean forward and inclined. As long as the hips are pushed far back, the subject will need to lean forward in order to keep the bar tracking over the middle foot

In the opposite case, when someone has short femurs. The hips can only be pushed back a little bit, before the weight starts to shift towards the heels. The knees will be placed more directly over or slightly behind the toes. Since the hips are only slightly pushed back, the upper body will remain very uppright, wich keeps the bar centered over the middle foot



(http://www.underdogstrength.com/how-to-squat-long-femurs/)

3.5. Foot placement

Over time, people has believed that we can target specific muscles by variating the foot placement for the loaded barbell squat (Clark, Lambert, Hunter, 2012) For example in proffesional cycling it is believed that the foot placement while perform a squat, should be equal to the width between the pedals on a bicycle and the feet should be in a parallel position, as while pedaling (Clark et.al, 2012) It appears to be small differences in muscle activation. The only muscles that report increased activation with wider stance is the gluteus maximus and the adductor longeus (McCaw& Melrose, 1999, Paoli, Marcolin & Petrone, 2009) the activation of the other muscles are affected by the barbell load.

3.6. Front squat

The front and the back squat are two different variants, although the same muscles are invovled, there are some differences in technique and muscle activity. In the back squat the bar is placed across the trapezius, wich allows the knees to flex untill the tighs are paralell to the floor. In the ascent phase, the hips and knees are extended until initial position is reached, (Baechle & Earle, 2000) In difference from back squat, the front squat involves placing the bar across the anterior deltoids and clavicles. The elbows should be fully flexed, in order to position the upper arms paralell to the floor, wich leads to a more "uppright" position for the upper body (Baechle & Earle, 2000) The front squat activates a similar amount of muscle mass as the back squat, but reportedly puts less compressive forces and lower knee extensor moments on the knee joint (Gullett et.al, 2009) Wich is one reason why subjects are able to lift greater loads for back squat (Gullett et.al, 2009) The front squat could therefore be considered for individuals with knee problems (meniscus and joint tears etc) and those with decreased shoulder mobility (Gullett et.al, 2009)

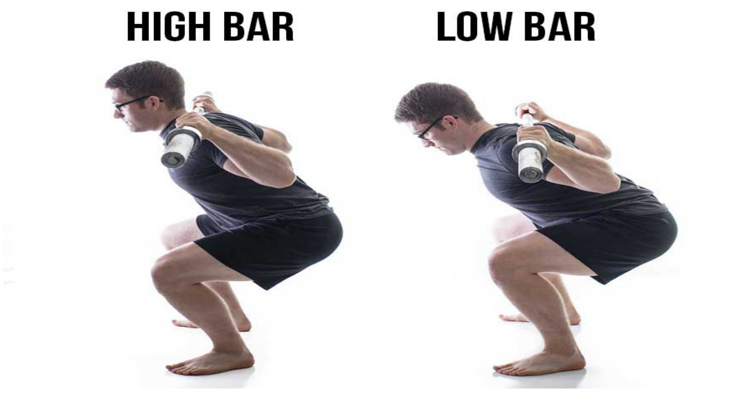
(https://scarysymptoms.com/2014/09/women-back-squat-long-femur-short-torso/)

3.7. High bar vs low bar

Back squat is considered a comon exercise in strength and conditioning in various sports. Perhaps the most common variants are, high bar back squat, low bar back squat and front squat (Escamilla et.al, 2001). The low bar squat (LBBS) is typically used in competitive powerlifting, as it often allows more weight to be lifted (O'Shea, 1985)

The main difference between the two back squat variants is the placement of the bar (Glassbrook et.al, 2017) The placement of a high bar squat (HBBS), is typically across the upper part of the trapezius muscles, while the LBBS is placed on the lower part of the trapezius, just above the deltoid . There is more force transfered through the hip joint in LBBS while there is more to the knee joint in HBBS (Swinton et al, 2012).

HBBS are often deeper than competitive powerlifting squats and leads to greater flexion in the hip, ankle and knee joints. The angle at peak knee flexion is reportedly smaller in the HBBS (70-90 degrees) compared to LBBS (100-120 degrees) The more forward leant LBBS, leads to a greater placement of the barbell over the center of mass, wich shortens the trunk lever arm and puts more weight on the stronger muscles of the hip, rather than the knee joint. The stress on the lumbars and ankle region is also higher in LBBS.A biomechanical analysis for the high bar and the low bar squats shows that competitive lifters achieve significantly greater flexion of the knee angle for the HBBS, and greater ankle ROM while performing a LBBS than less experienced and recreationally trained subjects (Glassbrook et.al, 2017) Olympic weightlifters are able to squat with greater ROM for the ankle joint, and for the LBBS, powerlifters attaine larger knee joint ROM. In all cases there are larger angels using HBBS. Athletes aiming to strengthen the muscles surrounding the hip joint should perform the LBBS while HBBS is more suited to olympic exercises such as snatch and clean, because of its more upright torso position, as it puts more force on the muscles around the knee joint (Glassbrook et.al, 2017)



(https://garagegymbuilder.com/low-bar-vs-high-bar-squats/)

3.8. *Squat depth*

A greater squat depth has the ability to increase the ROM on the ankle plantar flexors, hip and knee extensors. Assessed by relative muscle effort (RME) wich is calculated as the ratio of NJM to maximum voluntary torque matched for joint angle (Bryanton et.al, 2012) The quadriceps muscles it is apparently not affected by squat depth, rather the load, while both are significant for the hamstrings and gluteus muscles (Bryanton et.al, 2012)

When EMG activity is assessed at different squat depths (Partial, paralell and full squat) the contribution of the gluteus maximus in the concentric part is is significantly higher for full squats and parallel, than for partial reps. But no significant difference is found for vastus medialis, vastus lateralis, and biceps femoris (Caterisano et.al, 2002)

3.9. Box squat

The main difference in this exercise compared to a standard free weighted back squat, is that the performer, places a "box" or often a bench underneath before "sitting" on it for typically 1-2 seconds at the end of the eccentric phase. This removes the "stretch-shortening cycle that occurs in the standard squat (McBride et.al, 2010).
For example performing a countermouvment jump (CMJ) the stretch-shortening cycle leads to higher peak velocity, peak force and increased jump height (Mcaulley et.al, 2007) Heavy loaded barbell squats, follows the same movement pattern as the (CMJ) however, heavyer loads, are difficult to move with high velocity (Mcaulley et.al, 2007)
With the use of stretch-shortening cycle, higher loads can be lifted at a higher velocity of movement compared to in box squat where there is only concentric movement. This is explained by the fact stretching the muscle-tendons, lead to higher muscle activation at the start of the concentric phase. In terms of muscle activation and power production, the box squat is considered very similar to the standard back squat (McBride, 2010)

(https://physiolounge.co.uk/squats-king-exercises/box-squats/)

3.10. Chain

The use of chain for added resistance is often used in powerlifting and in other competitive sports where development of strength and power are essentials. (Baker & Newton, 2009)

Typically for a squat performed with heavy resistance, the barbell accelerates slowly in the early stages of the concentric phase as the external momentarm increases on the hip and knee joint. When adding a chain around the tip of each sides of the bar, the external load is reduced at the end of the eccentric phase where the majority of the chain is on the floor. This allows for a large muscle loading. In this way, the performer must operate near-maximal levels for larger parts of the lift. Baker & Newton, 2009 suggests that the use of chain allows the lifter to move more explosively and maintain a higher force production into the final part (lockout) of the lift. Different studies where the contribution of chain is set at 5-10% show no significant impact on movement velocity or the ground reaction force (Ebben, 2002, Coker, Berning and Briggs, 2006) But when the chain contribution is set to 35% it has a positive effect on 1 RM for the barbell squat (Mina et.al, 2016)

(http://www.crossfithuntsville.com/wednesday-14-september-2011/)

3.11. Elastic band

When an individual performs a heavy barbell squat, the highest force production is at the start of the concentric part of the lift (ascent) This is for a short time period. Even tough a 1 RM is performed, most parts of the lift are performed submaximally. This can be explained by the external moment arms of the hip and knee joint increases while the internal moment arm decreases during the eccentric phase of the lift. This leads to a defavourised force-length relationship as the muscles of the lower limb are stretched long in the deep squat position (Anderson et.al, 2008) Several studies shows that the use of elastic bands in combination with free weights can alter force and power production, compared to only free weights (Wallace et.al, 2006, Stevenson et.al, 2010) The elastic bands leads to higher movement velocity during the eccentric phase. The force production during the concentric phase is also likely to increase through a combination of increased reflex amplitudes and a greater use of elastic energy that is stored in the tendon units during the eccentric phase. This "awakens* the muscles and make sure that they work closer to maximal potential during the whole lift (Stevenson et.al, 2010)

(http://www.napatenaciousfitness.com/2014/10/27/elastic-band-training-vs-free-weight-training-whats-better)/

4. Machines

4.1. Smith machine squat

Typically, athhletes prefere free weights over machines because it is believed to be more effective in activating muscle mass in the trunk region and requires more stabilization and coordination,wich is closer linked to athletic movement (Haff, 2000) Altough for beginners, the smith machine is easier to use, and does not require a spotter when using heavy weights, as free weight squats (Haff, 2000) The movement pattern of the free weight and smith machine squat, is very similar, but one paralell track on each side of the bar, allows the barbell to be more stabilized as the bar path is fixed.
One study reports a trend for higher trunk muscle but lower quadriceps activation during the free weight squat, (Anderson & Behm, 2005), As there is lower stabilization demands, subjects usually lift higher loads in the smith machine compared to free weight (Cotterman, Darby & Skelly, 2005) For enhanced athletic performance the smith machine provides equal results to free weights (Sheppard, Doyle & Lee-Taylor, 2008)

(http://www.mipielsana.com/smith-machine-squat/)

4.2. Hack squat

According to Sigmon et.al, 1990, the hack squat is a great assistance exercise for the back squat.. The hack squat allows for eccentric and concentric contractions wich is essential for developing strength and power in the lower extremity, it is also effective when an athlete is suffering from a lower back injury and is unable to perform regular back squats or leg press (Stone & O'Bryant, 1987) Compared to the barbell back squat, the hack squat puts less pressure on the lower back and hip, and places it on the lower part of the quadriceps and knee joint (Stone & O'Bryant, 1987) There is no stabilization demand as in the barbell squat, the performer must simply push the weight upwards, while remaining in control of the movement. The hack squat is usually performed in a machine angeled posteriorly at 45 degrees. The force is supported through padded shoulder yokes and the back is typically placed on a padded board, this increases trunk support (Clark, Lambert, & Hunter, 2017) It is important to keep the balance on the heels without faling forward, therefore it is important to place the toes at the edge of the platform. If performed correctly, the hack squat can be extremely important in stregthening the muscles And connective tissue surrounding the knee joint (Sigmon et.al, 1990)

In comparison to the barbell back squat, the hack squat report similar muscle activity a part from decreased activity of the trunk muscles, but with lower stabilization demands, subjects are able to lift heavier loads and spend more time in the eccentric part (Clarke, Lambert & Hunter, 2012)

https://fitnessontheweekend.com/build-muscle/hack-squat-alternatives/

Hack squats can also be performed in a reversed position, making it more similar to front squat

https://maxedmuscle.com/gym-showdown-hack-squats-vs-regular-squats/

4.3. Leg press

similar to the barbell squat, the leg press is considered a closed kinetic chain exercise that is used by athletes to enhance sports performance (Escamilla et.al, 2001) it is a multi joint exercise, involving some of the largest and most powerfull muscles of the human body. It has the ability to fully extend the muscles of the knee and hip joint as it possesses biomechanical and neuromuscular similarities to several athletic movements such as jumping and running (Escamillia et.al, 2001) Compared to the barbell squat, leg press has the knee and hip joint moving through a shorter ROM (Rossi et.al.

2016) In completing a leg press movement, the knees moves through 90 degrees of flexion and extension, while the hips does not extend past 45 degrees, unlike the paralell squat where the knee flexes to about 120 degrees and the hips to about 20 degrees (Escamilla et.al, 1998) In leg press the performer is sitting more in a uppright position, whereas the barbell back squat has he/she is leaning more forward. In Leg press there is less stress on the lower back (Palmitier et al, 1991) Squats requires a more straight up/down movement, while in leg press the weight is pushed upwards and inclined often 45 degrees. (Wirth et.al, 2016)

4.4. Different variations

Several studies investigate the effect of different techniques in strength exercises. Perhaps the most standard variant of the leg press is the 45 degrees (LP45) with different foot placement (Escamillia, 1998, 2001) The hip and knee flexion at the concentric part of the movement activates the knee and hip extensors, wich are large and powerfull muscles, that are closely related to power production in athletic movements such as running and jumping (Escamillia, 2001) Therefore, the identification of muscle activity using different variants of the leg press, may lead to more optimized sports performance and prevent and rehabilitate more injuries. Similar to the barbell squat, the muscle activation in leg press is first of all affected by the load (Da Silva et.al, 2008) Gastrocnemius and RF measure higher values of activity during the standard LP 45 and the low leg press (LPL) at 90 degree hip flexion, compared to high leg press (LPH) at 125 degrees (Da Silva et.al, 2008) The quadriceps muscles report more activity for LP45 and LPL, while the LPH is more effective in training the gluteus muscles (Da Silva et.al, 2008) Wider stance also increases gluteus maximus activation (Escamillia et.al, 2001)

4.5. Foot placement

Athletes may chose a specific stance width while performing the leg press. Either because they want to target specific muscle group or because of injury. An athlete in the phase of reconstruction from ACL surgery, may chose a version of the leg press that puts less pressure on the pattelofemoral compressive force or tibiofemoral anterior shear force (Lutz et.al, 1993) Wide stance (WS) narrow stance (NS) High foot placement (LPH) low foot placement (LPL) are different variations of foot placement for leg press (Escamillia et.al, 1998) There is nor reported any differene in Q activation or compressive forces on the knee joint, but wider stance and higher foot placement, increases gluteus and hamstrings activation (Escamillia et.al, 1998)

5. Methods

5.1. Systematic literature review

Is a review of aviable literature that uses systematic methods to collect secondary data (Armstrong et.al, 2011) A systematic literature review contains, evaluation of research studies and their findings, qualitatively or quantitatively (Armstrong et.al, 2011) The review formulate broad or narrow research questions and identify studies that are directly related. These reviews are designed to perform a summary of the evidence related to the research question. For example, systematic reviews of randomized controlled trials are very important in practical application of evidence-based medicine (Centre of evidence based medicine, 2009)

Performing a systematic literature review, is typically more time and cost efficient than completing a new study. It is commonly implemented by health care proffesionals as it may examine clinical tests, health, social and environmental interventions (Petticrew & Roberts, 2006)

5.2. Inclution/exclusion criteria

* Articles must be published in scientificly approved databases (pubmed)
* Only studies where they assess the effect and/or compare one single exercise, not a combination of several exercises
* The publication year of the articles must be after 1990
* All studies included in this review are experimental studies, no reviews
* Population involves young to old adults between 16 and 80 years of age
* The population involve untrained individuals to highly trained athletes, but no bed laying or clinical patients
* Studies are limited to vertical jump and sprint, no horizontal jumps
* There must be access to the full text version of each included article

5.3. Search

The pubmed database where searched for relevant studies. In addition it was conducted a parallel search in google scholar, using the same words and combinations. As this also tracks relevant data that may not be published in pubmed. The combinations for each outcome is seen below:

(" Squat" OR "back squat" OR " barbell Squat" OR "Squats"OR "Leg press" OR "Hack squat" OR "Smith machine squat")

Hypertrophy:
AND ("Hypertrophy" OR "Muscle hypertrophy" OR "effect on hypertrophy" OR "Cross sectional area" OR "CSA" OR " CSA Quadriceps" OR thigh CSA" OR "quadriceps thickness" OR "thigh muscles" OR "thigh thickness" OR "thigh girth" OR "Muscle growth" OR " muscle size" OR "increase muscle size" OR "muscle thickness"

Strength:
AND ("Strength" OR "muscle strength" OR "1RM","strength performance" "OR "strength gains"

Athletic performance:
And ("athletic performance" "OR "enhancing athletic performance" OR "effect on athletic performance" OR "jumping performance" OR "jump" OR"Jumping", OR "squat jump", OR "vertical jump" OR "jumping ability" OR "CMJ" OR "sprint performance" OR "sprint" OR "sprinters" OR "sprint times" OR 40m sprint" OR "20m sprint" OR "speed" OR "running performance" OR "running speed" OR "running velocity"

When the first search was conducted, 189 articles appeared for hypertrophy, 2221 for strength and 1193 for athletic performance. As there was a large quantity of “strength studies”, more words where exluded for this outcome. The exlution of words was performed after reading the titles and some abstracts of articles appearing on the first 2-3 pages (best matches)
The search was narrowed until roughly 50 articles where left. These where all examined for relevance.

Since the first serach was too wide, articles containing the following words where excluded (The same words where exluded for all 3 outcomes) :

NOT (" Leg extension", OR "Leg extensions" OR "Leg curl" OR "Leg curls" OR "animal" OR "rat" OR "bench press" OR "review" OR "Protein" OR "Supplementation" OR "Biceps" OR "ingestion" OR "upper limb" OR "EMG" OR "muscle activation" OR "endurance" OR "hip thrust" OR "deadlift" OR "lunges" OR "testosterone doses" OR "creatine" OR "Blood flow" OR "drop set" OR "steroids" OR "carbohydrates" OR "nutrition" OR bed rest" OR "patients" OR "hemodynamic”)

In addition the "clinical trial" filter was used in pubmed

5.4. Data collection

Since there where more articles appearing in google scholar (100 000 +) , some longer combinations containing the words above where used in addition to those mentioned above, as this helped in narrowing the search. Similar articles appeared first as these where most cited.
After the abstract of the relevant articles where read, further examination of the "method" part was reviewed to assure if the articles complied to the inclusion/exclusion criteria.
The reference list of relevant articles was read, wich helped finding more data .
After the relevant studies where collected, they where divided into 3 categories, *hypertrophy, muscle strength and athletic performance.* Some studies assessed only one variable, others 2 or 3.

Amount of studies included in each category:

Hypertrophy: 9
Muscular strength: 14
Athletic performance: 21

6. Results

All 9 studies in this review assessing muscle hypertrophy after a period of systematic training, demonstrate that both the free weight and machine variants of the squat and the leg press exercise increases the CSA of the thigh muscles. The most comon intervention duration is 8-12 weeks, with 2-3 weekly sessions. Different units are used to express the effect of intervention. 4 studies use percent (%) when refering to the outcome (e.g quadriceps CSA +14.7%) while others effect size (ES) or P -value. This somehow complicates the comparison of the studies, altough they all report significant results. Untrained individuals achieves more hypertrophy than trained, and longer duration studies with higher volume seems more efficient.
There where some difficulties in finding hypertrophy studies for single exercises, wich was one of the inclusion criterias. This explains why only 9 studies where retrieved. There where only 1 study that singulary examined the leg press (Sale, Martin & Moroz, 1992)

Hypertrophy

Reference	Population	Exercise	Exposure	Results
Earp et.al, 2015	9 untrained men	Barbell back squat	Quadriceps (Q) CSA after 8 weeks of training 3 times per week	Q + 14.7%
Fonseca et.al, 2014	20 active males	Barbell back squat	Q CSA after 2 weekly sessions for 12 weeks. Difference between varied and constant rep range	C group + 11.8% QCSA V group + 9.4%
Schwanbeck et.al, 2008.	15 males, 21 females (22 +- 3yrs) With	smith machine squat, barbell squat.	Muscle mass and strength, extensors knee after 8 weeks	Muscle thickness for Q + 5.92% for Free weights

	previous weight training experience		training	(FW), 6.28 for smith machine (SM)
Blazevich et.al, 2003	15 male, 8 female athletes	Barbell back squat and front hack squat	muscle size and architerture after 5 weeks of training	Overall effect size (ES) in VL and RF was 1.08 SQ and 0.78 FHS
Colker, Swain & Lynch, 2002	18 male athletes (from 18 to 25 yrs)	Barbell paralell squat (PS) and barbell full squat (FullS)	CSA of the quadriceps muscles after training 2 a week for 6 months	PS experienced a trend for + QCSA (P = 0.0859) while FullS significantly + (0.0073)
Sale, Martin & Moroz, 1992	8 physically active males (mean age: 21.4yrs)	Leg press	CSA of the knee extensors after 19 weeks of training	CSA of the knee extensors +11%
Blomquist et.al 2013	17 Male sports science students	Back squat and shallow squat	CSA of the thigh	CSA 4-7% greater in full ROM squats
Chelly et.al, 2009	22 young male soccer players with no previous experience in RT (mean age: 17 yrs)	Barbell half squat	CSA of the tigh after 2 weekly sessions for 8 weeks	from 162 to 168 cm2 (no signf+)
Weiss, Coney, & Clark, 2000	38 healthy males (mean age: 21.2 yrs)	barbell back squat	muscle thickness and tigh girth after 7 weeks of training 3 groups 3-5RM (1), 13-15	Tigh girth + 1.10 cm for 1 + 1.40 cm for 2 and 3. Q thickness

			RM (2) and 23-25 RM (3)	+0.61cm for 1 RM,+ 0.43 cm for 2, + 0.55 cm for 3 H thickness + 0.40 cm for 1, + 0.14 cm for 2, + 0.20 for 3

Strength

There where significant improvements for strength in all 14 studies that where incuded both for free weights and machines. The majority of training interventions are lasting 8 weeks, where the shortest is 5 and the longest is 10 weeks. Machines seem to be more efficient in improving strength, as the highest increase was with leg press in Wirth et.al (30%) but the strength gains achieved using free weights are apparently more transferable to other exercises, while e.g leg press strength is more specific (Rossi et.al, 20016) 2 studies on the use of elastic bands and chain in the warm up, suggests that these could be important tools in further increasing 1 RM performance

Compared to hypertrophy, there is more studies assessing strength, as shorter interventions and less equipment is needed. There where also a greater balance between free weight and machine studies (11 vs 8), and several studies compare barbell squats with either leg press, smith machine squat or hack squat.

Reference	Population	Exercise	Exposure	Results
Fonseca et.al, 2014	20 active males	barbell back squat	1 RM strength after 2 weekly sessions for 12 weeks difference between constant (C) and varied (V) rep range	C group +22% V group +21%
Schwanbeck et.al, 2008.	15 males, 21 females (22 +- 3yrs) With previous weight training	smith machine squat (SM), barbell squat. (FW)	Muscle mass and strength, knee extensors after 8 weeks of training	SM group + 28 kg on SM, +19 kg on FW. FW Group + 23 kg on FW, +21 kg on SM

	experience			
Wirth et.al, 2016.	120 males (23.8 +-2.5 yrs)	Barbell squat and leg press	1 RM strength after 2 sessions per week 8 weeks	squat + 23.9% Leg press + 30.5%
Wirth et.al, 2016 (2)	78 students (39 exercise, 39 controls)	Barbell squat and 45 degree leg press	1 RM strength after 2 sessions per week 8 weeks	Squat and leg press sign +, no group difference
Rossi et.al, 2018	26 recreationally trained males (mean age: 22.0 yrs)	Barbell squat (BS) and leg press (LP)	1 RM strength on leg press and barbell squat	For the BS: + 76kg SG +54kg CombG +21kg LPG For the LP For the LP: No differ among groups (ES= 1.45-1.49)
Mina et.al 2016	16 recreationally active men	Barbell back squat with and without chain loaded variable resistance	1 RM strength after warm up with/without chain load (35%)	Chain improved 1 RM in 10 of 16 participants, average + 6.1%
Mina et.al, 2014	16 recreationally active men	Barbell back squat with and without elastic band	1 RM strength after warm up with/without elastic band load (35%)	Elastic band improved 1RM in 13 of 16 participants, average 7.7%
Blazevich et.al, 2003	15 male, 8 female athletes	Barbell back squat and front hack squat	isoknetic strength after 5 weeks of training	No sig difference in strength improvements
Rønnestad, 2004	14 recreationally trained men (age: 21-40)	Smith machine squat, (SMS) with and without vibration platform	1 RM strength	Vibration platform + 42.1 kg, SMS +36.3 kg

Chelly et.al, 2009	22 young male soccer players with no previous experience in RT (mean age: 17 yrs)	Barbell half squat	1 RM strength after performing 2 sessions weekly for 8 weeks	1 RM + 25%
Blazevich & Jenkins, 2002	9 elite male junior sprinters (Mean age:19 yrs)	Smith machine squat	Effect of 7 weeks high (HV) or low velocity (LV) RT on 1RM	HV+12.4% LV+11.8%
Styles et.al, 2016	17 professional soccer players (mean age: 18.3 yrs)	Barbell back squat	Effect of 6 weeks of HRT (85-90%) on 1 RM	1 RM from 125.4 to 149.3 kg
Bottaro et.al, 2007	20 inactive older adults (age 60-77yrs)	Leg press	Effects of 10 weeks RT high or low velocity at 60% of 1 RM	Leg press 1 RM improved 27.1% for high velocity, 26.7% in low velocity
Comfort, Haigh, Matthews, 2012	19 proffesional rugby players	Barbell back squat	1 RM before and after 8 weeks of training, 2 sessions per week	1 RM from 170,6 to 200.8 kg

Athletic Performance

During the search process, 21 relevant studies on the enhancing effect of different squat exercises on athletic performance was collected. The interventions are 6 to 12 weeks of duration. But there are also some studies on the acute effect of squats on jumping performance. As there where far more studies on this, than the other two outcomes (Hypertrophy and strength) the data collection was stopped at 21. Altough there where more studies that could have been included, they where excluded, because of their similarity to already included studies and publication dates. There are 11 articles on machine variants (5 on leg press). Since it was easier to find relevant data, it was possible to distinguish between the different variants (machines and free weights) to a greater degree than for the other outcomes . Once again there seem to be far more studies on the squat exercises than leg press. Possibly because athletic movements such as sprinting and jumping is typically assessed in well-trained individuals such as track and field athletes, soccer or rugby players and according to the data collected in this review, these individuals tend to practice squat exercises more than leg press wich more often is used by untrained subjects or elders (Pijnappels et.al, 2007, Delecluse, Roelants & Verschueren, 2003) Neverthless there is no clear evidence weather free weights or machines are more effecient for enhancing athletic performance as long as the practicioners perform a variant of the squat exercise with complete ROM (back, front, smith machine or hack squat) The leg press apparatus significantly increases muscle strength and hypertrophy, but it is clearly not as effecient for enhancing sprint or jumping performance. (Wirth et.al, 20016)

Reference	Population	Exercise	Exposure	Results
Marques et.al, 2015	122 Physically active adults (mean age: 20.5yrs)	barbell back squat	short sprint performance after 6 weeks of either squat, sprint or combined training	Squat and sprint improved 1,7 and 1.8%, combined training 2.3%
Wirth et.al, 2016.	120 males (23.8 +-2.5 yrs)	Barbell squat and leg press	squat jump, CM Jump, after 2 sessions per week, 8 weeks	Squat group + 14.2% SJ and 13.4% CMJ Leg press group

				+5.2% SJ and 3.3% CMJ
Wirth et.al, 2016 (2)	78 students (39 exercise, 39 controls)	Barbell squat and 45 degree leg press	squat jump, CM Jump, after 2 sessions per week, 8 weeks	Squat group + 12.4 SJ and 12% CMJ Leg press group + 3.5% SJ and 0.5% CMJ
Rossi et.al, 2018	26 recreationally trained males (mean age: 22.0 yrs)	Barbell squat and leg press	Vertical jump	SG (ES= 0.62) CombG (ES=0.48) LPG (ES=0.24)
Yetter & Gavin, 2008	10 strength trained men (Mean age: 22.3 yrs)	Barbell front and back squat	sprinting performance on 40m after performing progressive loads of FS or BS	BS produced 0.24 m/s + speed than FS and 0.18 m/s + than CG
Blazevich et.al, 2003	15 male, 8 female athletes	Barbell back squat and front hack squat	20 m sprint time and vertical jump after 5 weeks of training	No sign diffference among groups
Sheppard, Doyle & Lee-Taylor, 2008	18 elite male volleyball players (mean age: 19.6 yrs)	Barbell back squat and smith machine squat	peak and mean power, force and velocity at 25 and 50% + body mass	BS produced + mean power (11-17.6%) no other differences
Rønnestad, 2004	14 recreationally trained men (age: 21-40)	Smith machine squat, with and without vibration platform	CMJ performance after 5 weeks of training	vibration platform + 3.2 cm CMJ SMS + 1.4 cm

Delecluse, Roelants & Verschueren, 2003	68 untrained females (Mean age: 21.4 yrs)	Leg press and different unstable squat variations (WBV)	CMJ performance after 3 weeks of training	WBV + 7.6% CMJ, no change for LP and LE
Mina et.al, 2018	16 recreationally active men	Barbell back squat with and without elastic band	CMJ performance 30 sec, 4,8 and 12 min after 2x3 reps at 85% with or without elastic band	CMJ height + 5.3-6.5%
Chelly et.al, 2009	22 young male soccer players (mean age: 17 yrs) with no previous experience in RT	Barbell half squat	CMJ, SJ and the first and last 5m of 40m sprint time after 2 weekly sessions for 8 weeks	SJ+ 3.1cm, CMJ+2.5cm sign+ max velocity and time of first and last 5m on 40 m sprint
Comfort, Bullock and Pearson, 2012	24 rugby league players and 20 recreationally trained	Barbell back squat	Comparison of 1 RM strength and 5, 10 and 20m sprint time	Sign negtv r for Recrt in 5,10 and 20m (r=-0.60-0.62) stronger r after 5m. No sign r for rugby players and sprint time
Harris et.al, 2008	30 elite level rugby players	Front hack squat	Comparison of, force, velocity and power outputs at 20 and 90% in front hack squat and sprint time on 10, 30 and 40 meters	moderate relationship (r=0.32-52) among variables

Wisløff et.al, 2004	17 professional soccer players (Mean age: 25.7yrs)	Barbell half squat	Comparison of 1RM strength and 30m sprint time and vertical jump height	1RM correlated with 30m sprint time (r=0.71) and vertical jump (r=0.78)
McBride, Nimphius and Erickson, 2005	15 division 3 football players	Barbell back squat	The effect of heavy BS (3 reps at 90% of 1 RM) warm up on 40m sprint performance	Subjects ran 0.87% faster after performing heavy BS
Pijnappels et.al, 2007	17 older adults (Mean age: 71yrs)	Leg press	Comparison of strength, RFD and CMJ in fallers vs non fallers	Leg press force generated and RFD, major predictors for fallers
Lopez-Segovia et.al, 2011	14 u21 soccer players	Smith machine squat	Correlation between full squat power outputs and 30m sprint times	strong correlation with PO at 70kg SMS and 30m sprint time (r=0.79)

Blazevich & Jenkins, 2002	9 elite male junior sprinters (Mean age:19 yrs)	Smith machine squat	Effect of 7 weeks high or low velocity RT on 20m sprint time	20m flying start: +1.9% HV +2.4%LV 20m acc: +4.3 HV +2.9%LV
Hartmann et.al, 2012	59 men and women (Mean age: 24yrs)	Barbell back squat (BS), front squat (FS) and quarter squat (QS)	CMJ and SJ performance after 2 weekly sessions for 10 weeks	CMJ: FS+8.29% BS+7.79% QS-0.1% SJ: FS+7.19% BS+5.33% QS+2.68%
Luebbers, Fry, 2016	23 track and field athletes (20.1 +- 1.1 yrs)	Free weight squat (FWS) and smith machine squat	The Kansas squat test, measuring peak and mean power. Relative fatigue and lactate	FWS reported significantly + peak an mean power, no significant differencies in relative fatigue and lactate
Blomquist et.al 2013	17 Male sports science students	Deep squat (DS) and shallow squats(SS)	CMJ and SJ after 12 weeks of progressive load, 3 sessions per week	CMJ + 7.4% in SS, + 13.2% in DS SJ no sign in SS, +15% in DS

7. Discussion

7.1. Hypertrophy

When the aim is to increase muscle size and architecture, both free weights or machines are efficient. Unfortunatley, there was only found 1 study on leg press. Even tough it exists several studies where leg press is a part of the training program among other exercises on the same muscle groups (Wilkinson et.al, 2006 Verdijk et.al, 2009, Schoenfeld et.al, 2015) .Therefore they where not inculded, as it is difficult to assess the importance of 1 exercise in hypertrophy studies involving several exercises . One important notice, is that the participants in these studies typically has no or little RT experience or are elderly individuals (Wilkinson et.al, 2006, Verdijk et.al, 2009) Wheras squat studies included in the result table, are typically performed on well trained individuals and athletes (Blazhevich et.al, 2003 Colker, Swain & Lynch, 2017) and as we know, hypertrophy is more efficiently pronounced in untrained individuals (Ahtiainen et.al, 2003) This makes it hard to conclude weather free weights or machines provide better results . The longest intervention among the machines variants was in Sale, Martin & Moroz, 1992 of 19 weeks. This also reports the largest increase of knee extensor CSA (11%) wich was higher than any other machine squat or leg press experiment.

Altough muscle hypertrophy occurs at early stages, these results suggest longer periods of chronic training for significant results. This is supported by Narici et.al, 1996

Schwanbeck et.al 2008 and Blazhevich et.al, 2003 are the two very important studies, as they divide subjects into two groups of training either free weights or machines (hack squat or SMS) all participants performe the same volume of training. This allows for a direct comparison of machines (hack and SMS) and free weights. Neither of the two report a significant difference, wich indicates that both variants are equally efficient as long as the subjects are performing a "squat motion". The techniqual advantages of the smith and hack squat machine may compencate for the the free weights ability to activate more muscle mass. As the machines require no stabilization it may help the participants move the weight slower and in a more controlled fashion. The machines has a fixed

bar path. This may limit the possibility of e.g leaning forward at the presence of fatigue since bar is stuck, and the subject can not change its position to the bar without moving the feets.
Perhaps a study assessing the different parts of the quadriceps may find a difference between free weights and machines, as these studys simply compare the total girth of the thigh instead of different sites. Another issue in the hypertrophy studies, is the difference in measuring muscle growth. Some measure thigh girth, while others just the quadriceps thickness or CSA

All studies where the barbell squat is performed with full range of motion, demonstrate a positive effect on muscle hypertrophy.
There where 2 studies where the participants performed shallow squats (Chelly et.al, 2009 and Blomquist et.al, 2013) Chelly et.al, did not report a significant increase of thigh CSA, altough the participants where 17 year old soccer players with no previous experience in strength training. The CSA of the tigh increased 6 cm2 by average, but did not reach significant levels. In difference Blomquist et.al, 2013 reported a significant increase for the two proximal sites of the thigh, altough the overall effect was 4-7% greater for the deep squat group. The total volume may explain the results as Blomquist et.al completed 3 weekly sessions for 12 weeks (36 sessions), while Chelly et.al, only had 2 sessions for 8 weeks (16 sessions). Apparantley the higher volume in Blomquist lead to significant improvements despite their population being more experienced individuals. This once again supports the dose/response relationship for muscle hypertrophy (Narici et.al, 1996)
The superior effects of full ROM squats compared to shallow reps can be explained by the biomechanics of full squats to be more effective, as the increased ROM leads to a longer moment arm of the knee and hip joint and activates greater parts of the muscles on the front thigh and gluteus muscles (Muscle animations) EMG measurments also confirms that Q and gluteus muscles are more activated when the performer perform deep squats (Bryanton et.al, 2012)

In Earp et.al, 2015 participants increased their thigh CSA of +14.7% while performing heavy progressive training (75-90%) this was the greatest improvements among all included studies. Importantly the participants had no experience performing RT wich may partly explain the results. It represents the importance of full ROM squats, wich seem more important than the load, for untrained individuals.The study compared heavy back squats (75-90%) and light loaded jump squats (LLJS) of full ROM (0-30%) Both groups experienced similar hypertrophy for the quadriceps (14.7 vs 14.3%) The difference was found in the proximal region (closer to the joint axis) as the heavy loaded squats where more effective (VL +21.5 vs 10.6%) Earp et.al explains this

by the difference in joint position or muscle shortening speeds, while between the barbell and LLJS wheras the jump squat group significantly increased CSA in the distal region of the VL and VI. A combination of the two exercises could possibly form a balanced structure of the thigh muscles in beginners.
Fonesca et.al, 2014 completes a study of longer duration (12 weeks) with 2 sessions per week. The participants where recreationally trained. The CSA of the quadriceps did not experience the same hypertrophy as in Earp et.al, 2015, but achieved similar results (+11%) after 12 weeks as Sale, Martin & Moroz did for 19 weeks on a similar population. The result of these two suggests that the barbell squat is more efficient for hypertrophy than the leg press. On the other hand, Scwanbect et.al, 2009 only experienced 6% quadriceps growth in recreationally trained individuals after 8 weeks of barbell squats. Perhaps therse individuals had more training experience, as in Earp et.al they where only listed as “active males” wich does not explain their approach to RT. It must also be considered that Sale, Martin & Moroz is the only study on leg press compare and that these where completed 23 years prior to Earp et.al..

If the machines are as efficient in promoting muscle hupertrophy for the quadriceps is, it may not be affected by the stabilization demands of the free weight squat. Importantly, the main emphasis in some hypertrophy studies, is the growth of the thigh" wich would be the quadriceps ,hamstrings and adductors, some studies just measure the quadriceps (Earp,et al, 2015, Fonseca et.al, 2014) As measuring hypertrophy of the gluteus muscles is far more complicated. Since these are essential when lifting heavy weight especially for the squatting exercises, future studies on this could possibly distinguish the free weight and machine exercises. Factors such as foot placement or stance width chosed by participants,may influence the effect of exercise, as wide stance squat and high placement of the feet in leg press, reports significantly increased hamstring activity, while there is no difference in Q activation (Escamillia et.al, 2001) Difference in squatting technique can affect muscle activation, as subjects who lacks strength in the Q muscles, may still be able to lift heavy loads by compensating throug "rising the butt" at the start of the concentric part of the lift, wich deloads the Q muscles and alters glute activation (Crossley et.al, 2011)

7.2. Strength

As for strength, all studies report that systematic training of 5 to 10 weeks significantly increases 1RM. Subjects seem to increase their strength on apparates more effficient than free weights, but machine strength is more specific and not as transferable to other exercises (Rossi et.al, 2016)

Machines

Wirth et al, 2016, conducted two different studies, measuring the effects of following a 8 week strength training protocol on strength (1RM) and jumping performance. The participants where divided into two groups (leg press or squat) where they performed 2 sessions per week.

The leg press is unable to produce the same effects on jumping performance as the squat, but the strength gains in this study where greater for leg press than squat (30.5% vs 23.9%) it appears that the lower stabilization and technical demands of the leg press induces more rapid strength improvements for recreationally trained individuals. This suggests that leg press is a usefull equipment for individuals aiming to strengthen the muscles of the lower extremity. It can primarly be efficient for elders or untrained subjects as the barbell squat would require more techniqual work before using heavy loads. We must also consider the injury risk of each apparatus. The leg press and other machine equipments report lower risks of injury than free weights (Mazur, Yetman, Risser, 1993, Gray & Finch, 2015) Therefore it must be considered if the easier use, faster strength gains and lower injury risks for leg press outweighs the advantages of the squat exercises in certain populations.

Elders, can achieve achieved similar strength gains. In Bottaro et.al, 2007, 1RM leg press increased 27% after completing 10 weeks of training 2 times per week 1 RM. As a secondary finding this study tested the difference of high and low velocity of movement . As there where no significant difference in strength gains, there was a large difference in the increase of functional performance, as the high velocity group improved 42.8% in 30s chair stand (reps) compared to 6.05% for low velocity. There was also a significant difference for the 8- Fit-up-and-go test (15.31 vs 0.80%) this reccomends high velocity of movement in training programs designed for elders wich is supported by previous studies (Henwood & Taaffe, 2005, Hruda et.al, 2003)

Perhaps the main study for comparing the effects of leg press and squat where Rossi et.al, 2016. In their experiment, subjects where divided into 3 groups, performing either squats (SG), leg press (LPG) or a combination of the two (S-LPG) through a 10 week training period. The total volume was 6 sets per sessions at a intensity of 8-12 RM. Participants went through pre and post 1 RM tests on both the squat and leg press. Post results demonstrates a significantly greater transferiability of strength from the squat to the leg press as SG increased squat strength by 76kg (mean) compared to

21kg (mean) for the LPG, conversely there was no significant difference in 1 RM improvements for the LP machine between groups. This suggests that squat strength is more specific and requires more techniqual work, while for the LP it is suffisient to strengthen the knee and hip extensor muscles for increasing RM.
Rossi et.al offers one explanation, the squat group experience a greater ROM of the knee joint (+30 degrees) . At the end of the eccentric part of the LP there is 0 degree knee flexion, when hip flexion is 45 ,while for the squat at 45 degree hip flexion the knee flexion is aproximatley 35 degrees. These differencies in hip-to-knee joint angels leads to a greater activation for the biceps femoris in the concentric part of the squat, compared to LP (Escamillia et.al, 1998)

Smith machine is also a efficient tool for strength. In Schwanbeck et.al, 2009 they assessed the transferability of strength gains on the smith machine to a barbell squat after 8 weeks of training. As the participants training on the smith machine, where able to increase their 1 RM by 28 kg (mean) their strength simultaneously increased 19 kg on the barbell squat wich demonstrates only a 4 kg difference from the barbell group (+23kg) who additionally increased 21 kg on the smith machine. Altough it can be discussed if the participants (recreationally trained men) where more used to the barbell squat, therefore the effects of smith machine where very equal to the free weight squat, this was not reported in the study. This indicates that the barbell and smith machine very much resembles each other and offer similar effects that are transferable to other squat exercises.
There where similar findings for another study comparing BBS and SMS in Blazevich, 2003. Where a 7 week training period lead to similar strength improvements for both recreationally trained and well trained individuals. Both Scwanbeck and Blazevich report higher loads with the useof smith machine. Blazevich & Jenkins, 2002 did neither experience any difference between hack squats or BBS among professional sprinters, altough we must consider that sprinters typically may have more experience with the barbell than the hack squat machine. Neverthless it seems to be similar strength gains as long as the subject are performing a free weight or machine version of the squat exercise. LP may lead to greater relative results, but the strength is not as transferable to the squat exercises as vice versa.

Free weights

Two studies with well trainied individuals, using barbell back squat (Comfort, Haigh, Matthews, 2012 and Styles et.al, 2016) In Comfort et.al, the subjects where professional rugby players and where on average 45 kg stronger from the start, than the soccer players in Styles et.al, 2016. The rugby players improved their 1 RM by 30.2 kg, compared to 23.9 kg for the soccer players. In this case, perhaps the 2 week longer training period for the rugby players had an effect, but more importantly soccer players had a lower body mass and logically less muscle mass. These sports are different as soccer players spend more time running continiously, while rugby players tend to rest more during games, and perform explosive sprints and tackles. This may give the Rugby players an advantage as they are more used to performing maximal muscle effort, and their training habits does not negatively affect their 1 RM strength. The longer runs and endurrance training for soccer players could lead to fatigue wich inhibits strength gains. It is also possible that training at such a high intensity (85-90%) is to high for a period of 6 weeks, wich hampered the effects of the soccer players. Neverthless both studies present clear evidence that 2 sessions per week of squatting, signiiicantly increases 1 RM performance. And as we know from Rossi et.al, 2016 and Scwanbeck et.al, 2008, free weight strength exercises has a great transfer ability to machine exercises and other variants of the squat.

In Chelly et al, 2009 the participants performed half squats and reportedly increased their 1RM by 25% after a 8 week period. Altough this was the only study where the subjects did not perform at least a paralell squat, the strength improvements where not superior to studies where participants performed paralell or full ROM squats e.g Fonesca et.al, 2014 and Wirth et.al, 2016 (+ 22 and 23.9%). Overall the strength gains from using free weights seem more transferable to machines and athletic movements. There is no clear evidence that free weight squats are more effecient than for example smith machine squats, as these two transfer well to each other (Schwanbeck et.al, 2008) Altough further studies in the future could confirm this.

Chain

As for the use of varied resistance, Mina et.al, 2016 investigated the effect of implementing resistance chain in the warm up, before performing a 1 RM at the barbell squat exercise. The load of the chain (CLR) was set to 35% of the total load. As for the procedure, participants performed a standarized warm up of 8-10 repetitions at 50% , 3-5 repetitons at 70% and 2 sets of 3 repetitions at 85% of i RM. At the last two sets of the warm up (85%) half of the 35% CLR load was removed. The range of 35% contribution, meant that at a weight of 100kg, half of the 35 kg would be removed from the bar, leaving 82.5 kg with 35kg from the chains. This gave a total of 117.5 kg in the standing position and 100kg as a average through the lift.

As a result, 10 of the 16 participants, where able to increase their 1 RM with the use of CLR. No differences where found in peak or mean amplitudes of the knee extensors, neither during the eccentric or concentric phases of the lift. The knee flexion angle was significantly greater for the CLR. This may be associated with the importance of reducing bar velocity at the eccentric part of

the movement, to make sure they where able to stop before the ascent. Importantly none of the participants performed better than their previous 1 RM at the FWR condition, while the highest increase with CLR was at 10%, the mean value was 6.1% higher 1 RM with the use of CLR. During the 1 RM attempt, it was detected significantly higher activity during the eccentric phase for the VL, VM, RF and QF. The increase in 1 RM can not be explained by the mechanics of the lift. Importantly this study, did not assess the EMG activity of the hip extensors, wich is a important contributor to squat strength (Flanagan & Salem)
Torso angle is another possible factor that was not controlled between the two variants.

***Elastic Band**:*
Mina et.al, 2014 conducted a study on the effect of implementing the elastic band in the warm up of a 1RM trial for BBS. 16 recreationally active men at the mean age of 26 years the participants tried both conditions in a randomized order. The same procedure as the "chain" study was followed where they followed a standarized warm up and 2 preconditioning sets at 85% of 1RM, where half of the contribution from the elastic band was removed. They then attempted their previous 1 RM. The contribution of the elastic band was also set to 35% estimated by force platform. As a result, 81% (13 of 16) increased their performance by using elastic bands with a mean increase of 7.7% . Lower peak and mean angular velocity where observed both concentric and eccentric during the 1 RM attempt with elastic band. No differences where found in muscle activity, knee flexion angle or EMG amplitudes although eccentric and concentric velocity was reduced. The improvements in 1 RM is explained with the elastic bands ability to potentiate the neuromuscular system that enhances maximal lifting performance. The reduced eccentric velocity, enhances muscle activity of the VL, VM, RF wich in the concentric phase. The reduced velocity of the ascent phase can probably be explained by the load gradually increasing towards the top as a result of the elastic bands contribution. This study recommends the use of elastic bands in a warm up routine for athletes as it most likely enhances maximal squat performance.

7.3. Athletic performance

Jumping performance

There is clear evidence from the 11 studies in this review assessing the effect on jumping performance, that different squat exercises should be involved in training programs for individuals aiming to improve their jumping ability. Altough it is important to notice that the studies measure vertical and not horizontal jump performance, as this was part of the inclusion criteria. Previous studies demonstrates the positive effects of increasing 1 RM squat strength and horizontal jump performance, both as a warm up routine (Scott & Doherty, 2004) and after a 7 week training intervention (Morrissey et.al, 1998). Importantly these studies are mainly performed on athletes, that typically has RT experience and knows how to perform a techniqual correct squat. The ability of transferring power generated in the squat exercise to athletic movements is usually greater in athletes than untrained individuals (Liu, 2003). Once again the importance of deep squats seems evident. Hartmann et.al, 2012 compared the effects of barbell back, front and quarter squats on CMJ and SJ. Both FS and BS significantly increased jumping performance, with no significant difference between the two. While the QS was unable to have any effect on the tests even after 10 weeks of training 2 times per week. Blomquist et.al, 2013 also found full back squats to be more effective than shallow reps, but in this study the participants where able to increase CMJ using shallow reps (7.4%) opposite to Hartmann et.al, 2012. One reason for this, may be that the participants obtained a significantly higher training volume in their training period (36 sessions vs 20) wich suggests that partial squats with heavier loads also can increase CMJ tough clearly not as efficient as full ROM squats.

Similar to muscle hypertrophy, the importance of fully extending the knee and hip extensors seems , more important than the load being lifted, as QS are performed with significantly higher loads (Hartmann et.al, 2012)

The evidence found in Wisløff then becomes less important, as they only tested the correlation between vertical jumps and half squat 1 RM in soccer players. Even tough there was a strong correlation (r=0.78) there is reason to believe that subjects performing the strongest 1 RM full squats, are likely to be the strongest "half squatters" as well.

Wirth et al, 2016 completed two studies assessing the difference in effects of barbell squat and leg press on CMJ and SJ performance, there was a consistent effect for squats between the studies, only variating from 12 to 14.2% while for the leg press exercise did not significantly increase CMJ or SJ performance a part from the 5.2% of SJ in a group of 60 healthy men. A secondary finding was that the LP group presented a decreased RFD for the right leg, wich can not be explained by fatiguing

effects (Wirth et.al, 2016) The explanation of the different results for the squat and LP group, is that the body position while performing a squat, corresponds better to the jumping movement, as the similarities of the squat and the jump tests, more likely transfer to improved performance. The CNS apparentley transfer a high level of signals between the squat, CMJ and SJ compared to LP. The differencies in hip and knee angels and contraction type (unilateral or bilateral) seem to have a greater influence than increasing the strength of the kne and hip extensors. Altough the correlation between maximum dynamic strength and jumping performance is considered moderate to high (r=0.64 to 0.79) the importance of the squat exercise is evident.
Neverthless Pijnapples et.al, 2007 found leg press to have a positive influence in preventing falls for elders (71 yrs age) as there was a strong relationship between force generated in the leg press apparatus with decreased risk of falls and high CMJ scores. One of the reasons for the low amount of data collected on the leg press, is that studies involving leg press, also contains other exercises on the knee and hip extensors wich may effect the results. One example of this is (Pinto et.al, 2012) where the participants significantly increased CMJ performance by training leg press, leg extensions and leg curls. Delecluse, Roelants & Verschueren, 2003 found no effect of training leg press on young untrained females (21yrs) wich may suggest that the leg press is more effective in the elderly population, altough the duration of this study was only 3 weeks.
To conclude weather leg press is a efficient tool for enhanced athletic performance, further experimental studies with longer durations is needed.
Studies comparing BBS with the SMS or hack squat show no significant differences for jumping performance (Blazevich et.al, 2003,Sheppard, Doyle & Lee-Taylor, 2008, Luebbers & Fry, 2016) Luebbers & Fry used that Kansas city squat test, where the participants perform 15 speed reps at the phase of 1 rep per 6 sec with the load calculated by the formula(BM+1RM)x 0.70)-BM)
They found one difference between the SMS and FWS, wich was that FWS generated higher peak and mean power. One explanation could be that the athletes where able to move the bar faster, as they all lifted less weight for FWS while there where no difference in lactate levels or fatigue index. Sheppard, Doyle & Lee-Taylor, 2008 found similar results where the FWS generated higher mean power for volleybal players performing jump squats. Movement restrictions of the smith machine and the fact that the athletes where more comfortable using free weights could influence, altough SMS is also considered reliable instrument for power measurment in athletes.

As for varied resistance, Mina et.al 2018 found that implementing elastic band squats as a warm-uppositively influences CMJ performance, compared to a standard loaded back squat. The subjects completed 3 repetitions at either standard free weight (FW) or variable ressistance (VR), followed by 3 consecutive CMJ 30 seconds, 4, 8, and 12 minutes later. As for VR, the CMJ height was 5.3-6.5% higher, peak power was 4.4-5.9% higher, the rate of force development increased 12.9-19.1% and the peak concentric knee angular velocity was 3.1-4.1% higher. In addition the VL demonstrated 27.5-33.4% higher overall EMG activity at the concentric part of the lift. The improved CMJ performance is due to a increased RFD and peak power through the elastic bands ability to potentiate the nervous system in the same manner as it increases 1 RM strength performance.

Sprint

As for the other variables. Evidence for leg press is lacking. The relationship between 1 RM for the barbell squat and sprint times is not as strong as jumping ability, but still significant. Comfort, Bullock and Pearson, 2012 report a moderate to strong correlation (r=0.60) for recreationally trained males, while there was no correlation for Rugby players over a 20m sprint trial. One reason for these findings may be that the rugby players had a higher BM (96 vs 78 kg) and the first 5 meters of a sprint trial are more likely to be affected by relative strength than absolute strength, as the individual must accelerate its own BM from a stagnat position. There may also be a upper limit to where strength is a functional aid in increasing running performance, as strength gains at a high level increases body mass. The difference in sprint times is greater at 20m (0.09 sec) than 5m (0.03 sec) possibly, because the athletes possess better running technique and are able to generate more force at high velocity or the greater contribution of the stretch-shorteninng cycle wich is discussed in Baker & Nance, 1999 that limits the contribution of maximal muscle strength for longer sprint distances.

In Harris et.al, 2008 they performed a study on a similar population, with 40m sprinting time with the use of machine squat jump 1 RM. In difference subjects performed front squats. The relationship was weak to moderate (r=0.32-0.52) suggesting that slightly longer running distance may increase the relationship, altough it is still not strong for high level athletes.

One interesting finding is McBride et.al, 2009 where they tested 40 yard sprint dash, on proffesional american fotball players and found that subjects possessing a 1RM squat of 2.10 1RM/BM performed significantly better on 10 and 40 yard sprint trials. Supporting the evidence for relative strength importance on sprint performance. In difference the subjects performed squat to a 70 degree knee angle wich is 20 degree shallower than a standard powerlifting squat. Wisloff et.al also had their participants performing half squats and found a strong correlation with 30m sprint times (0.71) this suggest that shallow squats are more effective for sprint performance than jumping. Possible explanation can be that the biomechanics of a vertical jump is more similar to a squat than a running movement, and while sprinting, the individual is typically more upprised and does not descent to as low as 90 degree knee flexion angle. As stifness of the knee joint increases with running speed (Kuitunen, Komi & Kyrolainen, 2002) shallow squats are possibly more effective altough there are positive results for full ROM squats in a warm up routine as well. McBride, Nimphius and Erickson, 2005 found that heavy barbell squats (90%) had a potentiating effect on sprinting performance asas subjects ran 0.87% faster (5.35 vs 5.30 sec) after squatting 1 set of 3 repetitions.

Therefore a longitudinal study on shallow squats would answer the question weather squat depth is as important in running as jumping, since the strongest full ROM participants, typically is also stronger at 50 or 70 degrees knee flexion angle.

There is no clear indication weather free weights or machine variations are more effective as Blazevich, 2003 found no difference in improvements of 20 m sprint times between groups performing front hack squats or BBS for a 7 week training period. Blazevich & Jenkins 2002 also found SMS to effectively improve 20m sprint time. A secondary finding was that high velocity of movement is more efficient (+4.3%). Lopez & Segovia, 2011 reports a strong correlation between the power output in a SMS and 30m sprint times. Evidence for leg press on sprint times is lacking. Future studies should investigate this. Even tough free weights and squat variations seem more effecient for jumping performance, there may be differencies concerning sprint times, as for example shallow squats seem more effecient for enhancing running performance compared to jumping.

Sumary

*Systematic training of the tigh muscles using either free weight or machine variants of the squat exercise effectively induces muscle hypertrophy of the quadriceps and hamstrings with no clear difference between exercises (Blazevich et.al, 2003, Schwanbeck et.al, 2008)

* For significant hypertrophy to be achieved, squats should be performed with a full ROM (Chelly et.al, 2009,Colker, Swain & Lynch, 2017)

* Leg press is a effective tool for increasing muscle size and architecture for recreationaly trained individuals (Sale, Martin & Moroz, 1992)

* Individuals typically improve their 1 RM more effective on machines, as they are not as techniqualy demanding (Schwanbeck et.al, 2008, Wirth et.al, 2016)

* The strength gains achieved using free weights, are more related to athletic performance and transferable to machine strength, than vice versa (Rossi et.al, 2016)

* The use of chain and elastic band as varied resistance, in the warm up routine is recomended as it in the majority of cases increases the 1RM performance.

* Barbell squat is superiour to leg press for increasing CMJ and SJ performance (Wirth et.al, 2016, 1&2, Rossi et.al, 2016)

* Full ROM squats are more efficient for increasing jump performance than partial reps (Hartmann et.al, 2012)

* No significant difference between front squat and back squats effect on jumping performance (Hartmann et.al, 2012)

* Leg press is a major predictor for falls in the elderly population (Pijnappels et.al, 2007)

* The use of elastic band squats in the warm up routine, is recomended for athletes aiming to

improve their jumping performance (Mina et.al, 2018)

* Half squat 1RM strength is a strong predictor for sprinting performance is proffesional fotball players (Wisloff et.al, 2004)

* For young athletes with no previous RT experience, half squats can have a positive impact on jumping and running performance (Chelly et.al, 2009)

* Athletes aiming to improve their sprinting performance should trie to increase their 1 RM of either barbell, smith machine or hack squat, without increasing body weight (Blazevich et.al, 2003, McBride et.al, 2009, Comfort, Bullock and Pearson, 2012)

* Back squats seems more efficient as a warm up for improving sprint performance than front squats, for strength trained individuals (Yetter & Gavin, 2008)

8. Limitations and future studies

This litterature review was performed within a limited time period of (15 jan-31 May)
It was performed by 1 master student. A similar study performed by several individuals with higher competance may be more time efficient. It could also facilitate the interception of scientific articles and further relevant studies may be added, to answer the RQ more precisely. The inclusion criterias could have been more specific and only included e.g 8-10 week interventions. Long and short durations are difficult to compare.

A review assessing the effect on a more specific population (e.g athletes, recreationally trained or elders) would exlude many articles, but possibly provide more precise answers.

As the studies included, only contained the effect of single exercises (e.g squat or leg press) the eventual effect of combining exercises is not presented. Tough some exercises may be more efficient while combined with others.

There where many variants of the different exercises. The task would be more time efficient if only 1 free weight and machine variant was compared (e.g barbell squat and smith machine squat)

Future studies

Comparing the growth of hip and knee extensors could possibly answer if free weights are more efficient than machines, particularry leg press.
Several experimental studies of longer duration (+12 weeks) investigating leg press and the machine variants of the squat exercise. Preferably comparing free weights vs machines.
Several studies on the effeciency of single exercises on hypertrophy.
It would be interesting to compare the effect of groups performing one multi joint exercise e.g Barbell back squat vs several exercises e.g leg press, leg extensions, leg curls.
Investigating the effect of performing leg press combined with unloaded squat jumps on athletic performance is also interesting.

9. Conclusion

The evidence of this study suggests that performing free weight squats is superiour to machine leg press in enhancing athletic performance, however there is no clear evidence that free weight barbell squat is more effecient than smith machine or hack squats. Individuals improve 1 RM strength more efficiently by the use of machines, but strength gains in free weight exercises are more transferable to other exercises and athletic movements. There is not suffisient evidence to conlude if free weights or machines producec greater muscle hypertrophy.

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