SMITH MACHINE EXERCISE: THE KEY POINTS

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Review paper

Abstract
During the past two decades, sports scientists, coaches, therapeutic specialists, and other professionals are using the Smith Machine exercise (SME) to improve lower limb muscle strength. By overviewing the literature, the position of the bar, load, training volume (repetitions and sets), recovery (resting time), power, muscular work, and one repetition maximum (1-RM) are characteristics describing the SME and presented as variables on which the resistance training (RT) program periodization is focused. Therefore, the aim of the present brief review is to clarify this crucial point and to simplify the SME approach for the strength and condition trainers as well as for all other scientist involved in sports or therapeutic work. This brief review offers an insight into several recommendations on the key points, firmly based on relevant literature.

Key words: *external load, isotonic exercise, multi joint exercise, muscle power, muscle strength.*

Introduction

During the last decade, sports scientists used different training modality to improve lower limb muscle strength. Indeed, the typical exercise provides changing as well as motor control, skeletal and certainly cardio-vascular systems. One of the most popular forms of exercise for improving fitness in the gym and overall physical conditioning is the resistance training (RT) (Zelber-Sagi et al., 2014). The RT goals include: 1) Morphological transformation- increase in muscle mass, body composition change, body shaping, (Folland & Williams, 2007; Mitchell et al., 2013) 2) Muscle transformation - development of strength and power dimension (Häkkinen et al., 2002; Schoenfeld, Wilson, Lowery & Krieger, 2016) 3) Motor transformation - improvement of motor function and motor performance (Duchateau, Semmler & Enoka, 2006; Granacher et al., 2016). The most commonly used type of RT that cause the changes as mentioned above are free weights, and exercise machines (Cotterman, Darby & Skelly, 2005) and the usual question of a fitness trainer is whether they use one or the other, or combination of the two in their training programs. Training with free weights or with such a type of exercise is also called free form exercises, while exercises on the machines are called fixed form exercises (Baechle & Earle, 2000). From the aspect of the structural analysis of RT, there is a more than a noticeable difference between free weights and machines, not only seen from the aspect of biomechanical properties, but also from the neuro-muscular aspect. While free weights allow moves or patterns of motion that are similar to those in real life, exercises on the machines are performed under more controlled conditions and require less muscular coordination and postural control of the practitioner and thus less risk of injury (Anderson & Behm, 2005).

Also, a smaller adoption of the motor program and its correction in the progressive increase in resistance in the exercises performed on the machines is required (ACSM, 2009). Furthermore, when exercising on the machines, one doesn't need to be so concerned about the technique but to improve it, since the movement is solely directed or fixed on positive or negative work. This is certainly relevant and related to a different area as in rehabilitation programs. Although free weights activate more muscles, and both bodybuilders and coaches prefer them, the devices are simpler to use and do not require less assistance. This is especially important for beginners who lack in experience in RT. One of the most popular exercises used by strength-trained athletes for training leg musculature is a free weight squat. But to get a more stable exercise that will be similar to this, many trainers will use the Smith machine exercise (SME) (Schwanbeck, Chilibeck & Binsted, 2009). In this type of exercise, the type of movement is very similar to the free weight squat, but more controlled and safer to perform, meaning that barbell is stabilized in two parallel tracks. The SM can be found in gyms, recreation clubs, rehabilitation clinics and sports science laboratory. The SM has a bar that is fixed with the guides located on both ends of the bar itself. In this way, only fixed vertical trajectories are permitted, i.e. the movement can only be performed up and down, which is not the case with performing the same exercise with the free weight. There are also other SM variants with which the guides are not completely vertically positioned but at a slight angle. The bar on the SM has the dimensions and weight of the Olympic bar. In some variants of the

SM there is a counterweight, so the weight of the bar is almost negligible. It should also be emphasized that the SM is more secure for performing squats and other exercises (i.e., bench press, shoulder press, shrugs, upright row) because of the set of stands that makes it impossible for the bar to fall and injure the person performing the exercise. Consequently, the increase in safety and the multiple exercise options enhance the popularity of the SM as a resistance exercise mode (Cotterman et al., 2005). To provide some useful information and relevant scientific knowledge for strength trainers and all involved in sport, in this short overview, the squat on SM will be observed from a few possible contexts that characterize the exercise itself: position, load, training volume (repetitions and sets), recovery (resting time), power, muscular work, and one repetition maximum (1-RM) testing (Padulo, Laffaye, Chaouachi & Chamari, 2015). Besides these characteristics or variables that RT program periodization focuses on, there are others such as choice and order of exercise (Fleck & Kraemer, 2004).

Choice and order of exercise

As already mentioned in the introduction, the most commonly used types of strength training equipment are free weights and machine exercises. Within this division there are also two types of exercises, mainly considering the number of joints included in the exercises. Given that we can differentiate single (Bird, Tarpenning, & Marino, 2005) and/or multiple joint (Weiss et al., 2010) exercises. And single or multiple joint exercises are used alike in strength training programs, and the representation of each one can vary depending on the training goal that is intended to induce various muscular-neural changes. These two types of exercise vary naturally in the number of joints involved in performing an activity but also in the degree of muscular-neural activation and skill that is required to be completed (ACSM, 2009). There is no same muscular activation, for example, for the leg flexion and back squat. For the leg flexion, (movement performed in one joint), only the muscles of hamstrings are activated, while in the squat as multiple joint exercises, there is activation of more muscles or muscle groups (Maddigan, Button & Behm, 2014).

Indeed, the SM mainly involves multiple joint exercises (front and back squat, unilateral squat, lunges, bench press, shoulder push, etc.) In addition to selecting these exercises that are an indispensable part of the strength and fitness program, the SM is also used for scientific testing (Schick et al., 2010; Scott, Leighton, Ahearn & McManus, 2011; Vingren, Hill, Buddhadev & Duplanty, 2013). Although it is recommended that exercises involving large muscle groups to be put at the beginning of training (Sforzo & Touey, 1996), the current literature suggests that placement of exercises within a sequence should not be determined by the amount of muscle mass involved, but rather based on individual needs or movement patterns in greatest need of improvement (Simao, De Salles, Figueiredo, Dias & Willardson, 2012).
As reported by Arandjelovic (2012) the reason to prefer exercising on the SM rather than to use a free barbell are as follows: (a) exercises on the previously mentioned machine usually require less developed skilled in comparison to the same exercises performed with a free barbell, (b) by considerably decreasing the balancing demands, the advantage of the SM is to allow strength athletes to safely engage supramaximal loads in a limited range of motion when specialized, (c) a more controlled and safer environment for resisted plyometric exercise may be offered by motion constrained to a single degree of freedom. In summary, choice of training equipment and exercise should be dictated by personal preference, convenience, and person attitude to risk, however, machines like SM appear to offer a much lower risk of injury than free weights and therefore are preferable from a safety perspective (Fisher, Steele, Bruce-Low & Smith, 2011).

Position

There are many studies that involve biomechanical analysis of free squats with special focus on different techniques (width and angle of foot) (Escamilla, Fleisig, Lowry, Barrentine, & Andrews, 2001; Donnelly, Berg & Fiske, 2006), muscle activation (Paoli, Marcolin & Petrone, 2009; Yavuz, Erdağ, Amca & Aritan, 2015; Slater & Hart, 2017), speed of execution (Bazuelo-Ruiz et al., 2015; Balsalobre-Fernández, Kuzdub, Poveda-Ortiz & del Campo-Vecino, 2016), external load type and positioning (Gullett, Tillman, Gutierrez & Chow, 2008). Besides the entire technique diversity, the moment of equilibrium conditions that limit the possibility of modulating joint torques, muscle activities and joint reaction forces: the center of mass C of the system formed by the body of the user as well as the weighted barbell is bound to fall amid the heel and forefoot (Biscarini, Benvenuti, Botti, Mastrandrea & Zanuso, 2011). To overcome the mentioned limitation, the back should be held firmly by either a sliding or a lever machine. The SM is a training machine with previously described characteristics.

Accordingly, a wider range of exercise positions and at the same time more possibilities for modulating the distribution of muscle activity and joint loads are all offered by the SM squat, rather than the free squat itself (Biscarini et al., 2011). There are two types of squats, both with free weights and the SM: the front and back squat. Although both squats activate mainly the same muscle groups, the back squat is more commonly used and is more popular in athletes, primarily because of flexibility limitations, where front squat requires a considerable amount of flexibility in the shoulders, ankles wrists and hips. Also, for the front squat, an athlete is forced to hold the torso in the vertical position, meaning that there is no "cheat"

possibility as can be seen in the back squat. For these reasons, the athlete can lift more weight than in the front squat (Contreras, Vigotsky, Schoenfeld, Beardsley & Cronin, 2016).
This certainly does not mean that the front squat should not be implemented in strength and conditioning programs but on the contrary, it is preferable to do so. Gullett et al. (2008) studied differences in kinetic parameters between the front and back squat. It was found that the front squat produces significantly lower maximum joint compressive forces in the knee joint, as well as reduced lumbar stress compared to the back squat, which was achieved without compromising the muscular activity in the quadriceps and back. The authors suggest that the front squat can be a better alternative to the back for people with ligament injuries or meniscus. For the SM squat, there are many possible independent variables to consider for positioning such as the foot placement, slope of barbell bar guide, stance width, foot angle position, external load, execution speed, user's age, user's sex, and anthropometric parameters (Lee, Jung, Lee, & Lee, 2017).

As stated by Gullet et al. (2008) the back and front squat include the following procedures for a correct performance: the back squat includes putting the barbell across the shoulders on the trapezius, somewhat above the posterior aspect of the deltoids, leaving the hips and knees to slowly flex until the thighs are in a parallel position to the floor. This process is followed by extending the hips and knees until reaching the beginning or the starting position, with stressing on keeping the back flat, the heels on the floor, and the knees aligned over the feet. The front squat includes the lifter locating the barbell across the anterior deltoids and clavicles and fully flexing the elbows to position the upper arms parallel to the floor. The descending and ascending motions are same as in the back squat. The SM is safe for exercising and performing various movements, but as Padulo et al. (2015) pointed out the friction between the two steel bars on which linear motion moves should be observed more attentively. The friction coefficient of friction is 0.42µrd, while for static friction it is 0.78µrs. It is, therefore, necessary to regularly maintain the equipment with grease and to reduce possible variations in friction.

Load

The load is the amount of weight lifted or the resistance required for a person to perform an exercise (Kraemer & Ratamess, 2004). Before choosing load, it is necessary to know the barbell weight because it is dependent on the manufactory type. Therefore, it could be useful to assess the barbell weight with various approaches: for example, you can use a portable electronic strength gauge. In the next step, it's necessary to choose the optimal weight that is related to the aims: exercise goal, exercise age, gender, and practical experience (Padulo et al., 2015). But, with the aims mentioned above, load depends on other variables such as exercise order, volume, frequency, muscle action, repetition speed, and rest interval length (Kraemer & Ratamess, 2004).
The training load can be prescribed as a specified number of RMs or as a specified percentage of the 1RM. An RM is the heaviest load or resistance that can be lifted a certain number of times (Tan, 1999). Determining the load as a percentage of 1RM means that 1RM has to be defined for each exercise, and SM squat is no exception. Determining 1RM in trained people has no high risk of injury, but this is not the case with people who are beginners or individuals who are unfamiliar with strength and condition programs (Dohoney, Chromiak, Lemire, Abadie & Kovacs, 2002). However, with proper supervision, 1RM-testing protocols that include only one familiarization session and one testing session are sufficient for assessing maximum strength in untrained men (Levinger et al., 2009). Standardized 1RM testing protocol with a short warm-up and familiarization period is a reliable measurement to assess muscle strength changes regardless of muscle group location or gender (Seo et al., 2012).

Heavy loads of 70–90% of 1RM, with few repetitions, are the most efficient in enhancing maximum strength; and peak electromyographic activity in muscles, which reflects the level of neural activity, increases with increasing load (Newton et. al., 1997). Also, heavy load counteracts inhibition that prevents muscles from exerting more force than the connective tissues can tolerate (Lin & Chen, 2012). These loads will induce recruitment of fast-twitch motor units (Kawamori & Haff, 2004). On the other hand, light loads (30–50% of 1RM) with a high number of repetitions are suggested to stimulate adaptation to connective tissues and to maintain a balanced force between tendons and muscles (Bompa, 1999), and to result in gain muscle endurance (Kraemer et al., 1993). Lighter loads will induce recruitment of slow twitch fibers (Padulo, Mignogna, Mignardi, Tonni, & D'ottavio, 2012). As for motor unit recruitment due to external loading, the following mechanisms are occurring: more time is required for maximum force to recruit additional muscle fibers. Slow twitch motor units are recruited in the following order: type I slow twitch motor units, type IIx motor units and finally type IIa motor units. This mechanism is known as the size principle (Gregory & Bickel, 2005).

Nevertheless, if an explosive movement is to be completed in the shortest time possible, the neuron might select the fast twitch motor units to act first instead of recruiting the slow twitch motor units. The motor units with low activation thresholds are activated after the motor units with high activation thresholds. The previously mentioned phenomenon is known as a selective recruitment (Hodson-Tole & Wakeling, 2009). To put it in other words, adaptation due to the size principle may be a consequence of using a heavy load, whereas adaptation due to selective recruitment may result from explosive strength training. A comparison of

the resistance mechanism in the SM was made by Arandjelovic (2012).
According to the author's demonstration each resistance component, vertically constrained load, counterweight, and viscous, could be matched to a particular training context: 1) at low intensities (55–75% of 1 repetition maximum - 1RM) used in a strength-endurance training, viscous resistance containing the SM was found to offer advantages in respect to a constrained load and counterweighted designs, 2) at medium intensities (75–85% of 1RM) usually implemented in hypertrophy-specific training, the counterweighted SM design was found to offer the best choice in terms of high-force development and total external work performed, 3) at high training intensity (90–100% of 1RM), the optimal prescription was more dependent on the specific athlete's weaknesses, emphasizing the need for continual supervision of the athlete's force production capabilities.

Training volume

The training volume refers to the total amount of individual's work during a training session, or to be more precise the total weight lifted in a training session. The previously said can be precisely determined by calculating the work done in joules (i.e., force × distance). However, the total repetitions and volume load (or total load) are simple estimations for training volume used rather more frequently as follows: (a) total repetitions = sets × repetitions; (b) volume load = sets × repetitions × weight used (Tan, 1999). The most favorable design of strength training programs for resistance-trained athletes is quite important due to the proven fact that performing at a higher volume is rather less effective and efficient than performing at a higher volume (González-Badillo, Gorostiaga, Arellano & Izquierdo, 2005). The set can be defined as the number of repetitions performed consecutively without any rest, and the number of sets selected per exercise should vary depending on the training goals, (Kraemer & Ratamess, 2004; Schoenfeld, 2010).

Superior strength gain occurred following 3 set strength training compared with single set strength training in women with basic experience in RT (Schlumberger, Stec & Schmidtbleicher, 2001). In men, both 1 set (to failure) and three sets of weight training can result in statistically significant gains in muscular strength, but three sets have demonstrated greater gains in strength than a single set in recreationally trained men (Rhea, Alvar, Ball & Burkett, 2002). Moreover, three sets of strength training on lower body muscles is superior to 1 set during the strength training in untrained men, but it seems there is no difference between one set and three sets in the upper-body muscles during this first phase of adaptation to the strength training (Rønnestad, Egeland, Kvamme, & Refsnes, 2007). Repetition duration refers to a time required to complete each phase of a repetition. For example, a repetition consisting of a 3-second negative phase and 3-second positive phase is a 3s:3s repetition duration (Carpinelli, 2011). In SM exercise should be performed at a repetition duration that maintains muscular tension throughout the entire range of motion, what is not the case for free weights and ballistic movements, because of tension removal from the muscle which can apply greater forces through joints and therefore causes a greater potential for injury (Fisher, Steele, Bruce-Low & Smith, 2011).

Recovery

Training intensity is one of the most important variables to consider when designing a RT program aiming to target maximum strength (Tan, 1999). Training intensity is directly related to the load lifted in combination with sets and repetitions. By manipulating the intensity, the number of repetitions and sets, and the duration of the rest periods, training may be designed to target specific physiological adaptations to enhance the ability to sustain force production (Whyte, 2006). The time it takes to relax between exercises, sets, and repetitions largely depend on several factors and vary from trained and untrained person.

A significant role in recovery rates has physical condition and experience in certain exercises. Trained individuals demonstrate a high ability of energy transfer in cells and increased neuro-muscular adaptation to the stress caused by various exercise on the equipment, while this is not the case with beginners and people who are poorly trained. Recovery rates are highly associated with aerobic endurance performance of an athlete, where faster recovery means reducing rest intervals and increasing the total load lifted during training.

Several key points are proposed by Senna, Salles, Prestes, Mello & Roberto (2009) for RT recovery: 1) significant declines in the number of repetitions consequently occurred to having a shorter rest interval between the sets and exercise in RT sessions for upper and lower body, 2) longer rest intervals seemed necessary to avoid significant declines in the number of repetitions, mainly for last exercises, 3) the volume of repetitions or total work is an important variable when maximal strength is desired. Longer rest intervals are necessary to achieve specific volumes.

The rest interval influences the relative contribution of the following three energy systems (Kraemer & Ratamess, 2004): 1) Strength and power training predominantly stress the ATP-PC system, 2) hypertrophy/strength is supported mostly by energy provided by ATP-PC and glycolysis, with minor contributions from aerobic metabolism, and 3) local muscle endurance training involves a higher contribution of energy from aerobic metabolism. When training for muscular strength with loads smaller than 90% of 1RM (up to 50%) for multiple sets, 3 to 5 minute rest intervals are necessary to maintain the number of repetitions performed per set within the prescribed zone without any great reductions in training intensity, while, when training goal is muscular hypertrophy, the combination of moderate-intensity sets with short rest intervals of 30–60 seconds might be most effective due to greater acute levels of growth hormone during such workouts (De Salles et at., 2009).

Power

The time to move the different RT loads, the range of movement completed over each repetition, the velocity reached during such movements, and the power exerted at each load is especially useful to control the training process (Busca & Font, 2011). Most of the movements in sports and RT mostly depend on force and velocity. The product of force and velocity is power, and it is of the most effective measures of athletic performance (Haff & Triplett, 2015; Cormie, Mcguigan, & Newton, 2010). No matter what the type movement analyzed (e.g., leg movement in the squat), power output may be computed as the product of force times velocity (Samozino, Morin, Hintzy & Belli, 2008; Padulo et al., 2017). Following equations can be used to calculate velocity (v), force (F) and power (P) Bosco et al., 1995):

The velocity (v) $m \cdot s^{-1}$ during an elementary measurement of displacement (Δd):

$$v = \Delta d \times \Delta t^{-1}$$

where Δt is the time in seconds to perform the elementary displacement. The acceleration (a) $m \cdot s^{-2}$ can be derived as follows:

$$a = \Delta v \times \Delta t^{-1}$$

where Δv is the difference between the velocity of the considered elementary displacement and the velocity of the preceding elementary displacement. The corresponding force (F) in Newton can be calculated as follows:

$$F = (m \times g) + (m \times a)$$

where m is the mass of the load and g is the acceleration due to gravity ($9.81 m \cdot s^{-2}$). Finally, the power (P) in watts, can, therefore, be computed as follows:

$$P = F \times v$$

The maximum power output (P_{max}) is the highest power output value among the measurements at several different loads, whereas the optimal load is the load at which the maximum power output is achieved (Newton & Dugan, 2002). Improving power output during sports performance is one of the most important goals for strength and conditioning programs (Baker, 2001). Control of not only power but force can be necessary to determine the quality of an exercise workout or RT program, and to understand kinetic (e.g., power) and kinematic (e.g., velocity) variables can help characterize the workout. Also to decide the weight on the bar (Comstock et al., 2011).

The accurate and precise assessment of force and power are fundamental for sports testing, training, and rehabilitation (Crewther et al., 2011). Two of the most commonly used devices to calculate power through force and velocity variables in SM are linear position transducers (i.e., administered force is multiplied by velocity, obtained as displacement over time, resulting in a power–time curve; Cormie, McBride & McCaulley 2007) and force plates (i.e., force is measured directly as ground reaction by means of the plate; Cormie et al., 2007). These devices are equally used to calculate maximal power output in the upper (Wilson, Murphy, & Giorgi,1996; Garnacho-Castaño, López-Lastra, & Maté-Muñoz, 2015) and lower limbs (Comfort, Allen, & Graham-Smith, 2011; Padulo et al., 2013). There are several methods to measure power output in RT exercises (Hori, Newton, Nosaka, & McGuigan, 2006): 1) calculation from barbell displacement and known mass (barbell and subject's body mass), 2) calculation from barbell displacement and known mass (barbell mass only), 3) calculation from ground reaction force and known mass (barbell and subject's body mass), and 4) calculation from barbell displacement and ground reaction force.

Muscular work

Muscle activity in the SM squat depends primarily on multiple factor factors such as the training position, training volume, load, and speed and is mainly evaluated by surface electromyography (sEMG) (Lee et al., 2017; Sakamoto, Sinclair, & Naito, 2017). Surface electromyography provides easy access to physiological processes that cause the muscle to generate force, produce movement and accomplish the many functions that allow humans to interact with the world (De Luca, 1997; Sharma, Veer & Agarwal, 2014). sEMG can be used to study muscular activity with noninvasive method (Gioftsos et al., 2016; Samani, Srinivasan, Mathiassen & Madeleine, 2016) and with needle electrodes (invasive method) (Gurney et al., 2016; Ibrahim, Gannapathy, Chong & Isa, 2016). Even though there are many limitations with surface electrodes (Hug, 2011), needle electrodes are more discomfort to the subject and not always necessary for muscular activity assessment.

Using sEMG several muscle activations can be observed when performing the SM and free weight squat: quadriceps, hamstrings, gastrocnemius, and the gluteus maximus with the activity of hip and ankle joints, abdominals, and spinal erectors as well (Escamilla, 2001; Delavier, 2005; Schwanbeck et al., 2009; Maddigan et al., 2014). Although the FW squat by its structure is similar to the SM squat, there are still differences in muscular activation, mainly in the trunk. As stated earlier, the SM allows performing more stable squat than using an FW squat, and therefore less trunk activation will occur. Anderson and Behm (2005) in their research confirm above, where sEMG activity of the trunk musculature to be greater during the free weight squat than SM squat. When comparing individual muscles in the study from Schwanbeck et al., (2009) 3 leg muscles had significantly higher activation in the free bar squat when compared with the SM squat (gastrocnemius (34%), biceps femoris (26%), and vastus medialis (49%)). When a squat is performed on the SM, the practitioner can easily lean on the bar while performing the movement, and thus quickly sets foot in front of the vertical motion. This kind of foot-placing results in the position which is behind the toes. Because of the need for less stability for performing the SM squat, there are changes in the production force and inclusion of muscle groups, which is resulting in increased weight lifted (Cotterman et al., 2005, Schwanbeck et al., 2009). Adding a vibration as possible efficient training stimulus might result in a tendency of superiority of squats, performed on a vibration platform in comparison to squats without vibrations with respect to maximal strength and explosive power, considering the external load is similar in recreationally resistance-trained men (Rønnestad, 2004).

One repetition maximum - 1RM

Mechanical assessment and analysis of weight-room (i.e. squatting) and sport-specific movements (i.e., throwing and jumping) by using technology (i.e., force plates, position transducers, accelerometers) may provide strength and conditioning coaches with the tools that are required to improve evaluation methods for creating comprehensive athlete profiles which effectively influence programming (McMaster, Gill, Cronin & McGuigan, 2014). Even though the methods for evaluating maximal muscular force, such as force plate (Dello Iacono, Padulo & Ayalon 2016), isokinetic devices (Bridgeman, McGuigan, Gill & Dulson, 2016), rotary encoders (Drinkwater, Moore & Bird, 2012) and linear position transducers (Hansen, Cronin & Newton, 2011) are reliable and quite precise, they all require methodological expertise and they are pricey. Their use is often limited to laboratory settings, and most of coaches and athletes are lacking in access to most them (Rahmani, Samozino, Morin & Morel, 2017).

The one-repetition maximum (1RM) is the maximal amount of weight that can be lifted in one repetition (Brown & Wier 2001), and 1RM testing is the gold standard for assessing maximal muscular force in nonlaboratory settings (Levinger et al., 2009). The 1RM test was used as a maximal strength test by most of strength and conditioning professionals because it is not demanding as regards to expensive equipment and it reflects dynamic strength, necessary for competitive sports (Demura, Miyaguchi, Shin, & Uchida, 2010). Calculation of 1RM can be executed by a direct or indirect method. Direct method refers to the determination of 1RM to proceed over subsequent trials in which the amount of weight which should be lifted is increased stepwise until the subject fails to produce a full range movement (Niewiadomski et al., 2008). Indirect method refers to 1RM calculated by using sub maximal loads. The latter method is assumed more convenient and safer for untrained persons (Cadore et al., 2012). Besides, using sub maximal loads for 1RM prediction resulted for coaches and sports scientists in a considerable decrease of the amount of time required for testing compared to the direct method (Chapman, Whitehead & Binkert, 1998). Diverse prediction equations have been designed for calculating 1RM using sub maximal loads. The previously mentioned equations are specific to variables like age range, gender, muscle group measured, a technique in which the muscle group strength is assessed (ie. free weights or machine exercises), anthropometric parameters, ethnicity, and training status (Abadie & Wentworth, 2000; Padulo et al., 2015).

Prediction equations have been shown to be more or less accurate, depending on the loads and the repetitions used in testing (Mayhew, Barnett, Schutter & Bemben, 1995). As far as the link between sub maximal repetitions and 1RM estimation is regarded, the higher the load for performing the submaximal set, the more accurate the prediction of 1RM (Padulo et al., 2015). The research has shown results referring to 4-6 RM as more accurate in predicting than 10 or more RM. (Dohoney et al., 2002; Whisenant, Panton, East & Broeder, 2003). The available literature indicates that certain mathematical models are proposing to accurately calculate 1RM based on load and repetition number performed by a person (table 1).

Table 1 Prediction equations for estimation of 1RM.

Author	Equation
Landers (1985)	1RM = (100 × Load) ÷ (101.3 – 2.67123 × number of repetitions)
Lombardi (1989)	1RM = Load (kg) × number of repetitions (0.1)
O'Conner et al. (1989)	1RM = Load × (1 + 0.025 × number of repetitions)
Brzycki (1993)	1RM = Load ÷ (1.0278 – (0.0278 × number of repetitions))
Wathen (1994)	1RM = (100 × Load) ÷ (48.8 + (53.8 × e-0.075 × number of repetitions))
Epley (1995)	1RM = Load (kg) × (1 + 0.0333 × number of repetitions)
Mayhew et al. (1995)	1RM = (100 × Load) ÷ (52.2 + (41.9 × e-0.055 × number of repetitions))
Baechle (2000)	1RM = Load × (1 + (0.033 × number of repetition))

As indicated, (Naclerio, Jiménez, Alvar & Peterson, 2009) the following recommendations should be taken into account when assessing 1RM: 1) Linear equations are less precise with both heavier weights (i.e. more than 95%of 1RM) as well as with lighter weights (i.e., lower than 70% of 1RM). 2) The use of light weights that allows more than ten repetitions is not recommended, particularly among persons who aim to train for maximal strength adaptations. 3) Sub maximal tests are more precise with single joint assistance exercises. The most applicable formulas are considered to be the Mayhew formula, (upper body) and the Wathen formula (lower body). 4) When using traditional machines, the Brzycki formula has shown to be a good correlation with the 1RM. 5) Testing with sub maximal weights can be quite useful for both young and older people, not used to regularly train with maximum loads. Finally, an innovative approach for the indirect determination of 1RM is that based on the force-velocity curve as determined by using force and velocity values collected during a strength test with at least three incremental submaximal loads (Picerno et al., 2016). With respect to prediction equations, such approach can be considered subject-specific and independent from expertise, exercise type or population.

Conclusion

In this Brief review, we have brought together some of the current findings relevant to the use of SM as an exercise, especially the SM squat in RT programs. We think that these articles may be of interest to sports scientists, coaches, therapeutic specialists, and other professionals to use SM in lower limbs strength and power assessment.

References

Abadie, B.R., & Wentworth, M.C. (2000). Prediction of one repetition maximal strength from a 5-10 repetition submaximal strength test in college-aged females. *Journal of Exercise Physiology Online, 3*(3).

Anderson, K., & Behm, D.G. (2005). The impact of instability resistance training on balance and stability. *Sports Medicine*, *35*(1), 43-53.

Anderson, K., & Behm, D.G. (2005). Trunk muscle activity increases with unstable squat movements. *Canadian Journal of Applied Physiology*, *30*(1), 33-45.

Arandjelovic, O. (2012). Common variants of the resistance mechanism in the Smith machine: analysis of mechanical loading characteristics and application to strength-oriented and hypertrophy-oriented training. *The Journal of Strength & Conditioning Research, 26*(2), 350-363.

Baechle, T.R., & Earle, R.W. (2000). Essential of Strength and Conditioning. Champaign, IL: Human Kinetics.

Baker, D. (2001). Acute and Long-Term Power Responses to Power Training: Observations on the Training of an Elite Power Athlete. *Strength & Conditioning Journal*, *23*(1), 47-56.

Balsalobre-Fernández, C., Kuzdub, M., Poveda-Ortiz, P., & del Campo-Vecino, J. (2016). Validity and reliability of the push wearable device to measure movement velocity during the back squat exercise.*The Journal of Strength & Conditioning Research, 30*(7), 1968-1974.

Bazuelo-Ruiz, B., Padial, P., García-Ramos, A., Morales-Artacho, A.J., Miranda, M.T., & Feriche, B. (2015). Predicting maximal dynamic strength from the load-velocity relationship in squat exercise.*The Journal of Strength & Conditioning Research, 29*(7), 1999-2005.

Bird, S.P., Tarpenning, K.M., & Marino, F.E. (2005). Designing resistance training programmes to enhance muscular fitness. *Sports medicine, 35*(10), 841-851.

Biscarini, A., Benvenuti, P., Botti, F., Mastrandrea, F., & Zanuso, S. (2011). Modelling the joint torques and loadings during squatting at the Smith machine.*Journal of Sports Sciences, 29*(5), 457-469.

Bompa T.O. (1999) *Periodization Training for Sports: Programs for Peak Strength in 35 Sports*. Champaign, IL: Human Kinetics.

Bosco, C., Belli, A., Astrua, M., Tihanyi, J., Pozzo, R., Kellis, S., Tsarpela, O., Foti, C., Manno, R., & Tranquilli, C. (1995). A dynamometer for evaluation of dynamic muscle work. *European Journal of Applied Physiology & Occupational Physiology*, *70*(5), 379-386.

Bridgeman, L.A., McGuigan, M.R., Gill, N.D., & Dulson, D.K. (2016). Test-Retest Reliability of a Novel Isokinetic Squat Device With Strength-Trained Athletes. *The Journal of Strength & Conditioning Research, 30*(11), 3261-3265.

Brown, L.E., & Weir, J.P. (2001). ASEP procedures recommendation I: accurate assessment of muscular strength and power. *Journal of Exercise Physiology, 4*(11), 1-21.

Brzycki, M. (1993). Strength testing—predicting a one-rep max from reps-to-fatigue. *Journal of Physical Education, Recreation & Dance*, *64*(1), 88-90.

Busca, B., & Font, A. (2011). A low-cost contact system to assess load displacement velocity in a resistance training machine. *Journal of Sports Science & Medicine, 10*(3), 472.

Cadore, E.L., Pinto, R.S., Brentano, M.A., Silva, R.F., da Silva, E.M., Spinelli, R. & Kruel, L.F.M. (2012). Prediction of one repetition maximum load by total and lean body mass in trained and untrained men. *Medicina Sportiva, 16*(3), 111-117.

Carpinelli, R.N. (2011). Assessment of one repetition maximum (1RM) and 1RM prediction equations: Are they really necessary. *Medicina Sportiva, 15*(2), 91-102.

Chapman, P.P., Whitehead, J.R., & Binkert, R.H. (1998). The 225-1b Reps-to-Fatigue Test as a Submaximal Estimate of 1-RM Bench Press Performance in College Football Players. *The Journal of Strength & Conditioning Research, 12*(4), 258-261.

Comfort, P., Allen, M., & Graham-Smith, P. (2011). Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *The Journal of Strength & Conditioning Research, 25*(5), 1235-1239.

Comstock, B.A., Solomon-Hill, G., Flanagan, S.D., Earp, J.E., Luk, H.Y., Dobbins, K.A., ... & Vingren, J.L. (2011). Validity of the Myotest® in measuring force and power production in the squat and bench press. *The Journal of Strength & Conditioning Research, 25*(8), 2293-2297.

Contreras, B., Vigotsky, A.D., Schoenfeld, B.J., Beardsley, C., & Cronin, J. (2016). A comparison of gluteus maximus, biceps femoris, and vastus lateralis electromyography amplitude in the parallel, full, and front squat variations in resistance-trained females. *Journal of Applied Biomechanics, 32*(1), 16-22.

Cormie, P., McBride, J.M., & McCaulley, G.O. (2007). Validation of power measurement techniques in dynamic lower body resistance exercises. *Journal of Applied Biomechanics, 23*(2), 103-118.

Cormie, P., Mcguigan, M.R., & Newton, R.U. (2010). Adaptations in athletic performance after ballistic power versus strength training*. Medicine & Science in Sports & Exercise, 42*(8), 1582-1598.

Cotterman, M.L., Darby, L.A., & Skelly, W.A. (2005). Comparison of muscle force production using the Smith machine and free weights for bench press and squat exercises. *The Journal of Strength & Conditioning Research*, *19*(1), 169-175.

Crewther, B.T., Kilduff, L.P., Cunningham, D.J., Cook, C., Owen, N., & Yang, G.Z. (2011). Validating two systems for estimating force and power. *International Journal of Sports Medicine, 32*(04), 254-258.

De Luca, C.J. (1997). The use of surface electromyography in biomechanics*. Journal of Applied Biomechanics, 13*(2), 135-163.

De Salles, B.F., Simao, R., Miranda, F., da Silva Novaes, J., Lemos, A., & Willardson, J.M. (2009). Rest interval between sets in strength training. *Sports Medicine, 39*(9), 765-777.

Delavier, F. (2005). *Strength Training Anatomy.* Champaign, IL: Human Kinetics,

Dello Iacono, A., Padulo, J., & Ayalon, M. (2016). Core stability training on lower limb balance strength. *Journal of Sports Sciences, 34*(7), 671-678.

Demura, S., Miyaguchi, K., Shin, S., & Uchida, Y. (2010). Effectiveness of the 1RM estimation method based on isometric squat using a back-dynamometer. *The Journal of Strength & Conditioning Research, 24*(10), 2742-2748.

Dohoney, P., Chromiak, J.A., Lemire, D., Abadie, B.R., & Kovacs, C. (2002). Prediction of one repetition maximum (1-RM) strength from a 4-6 RM and a 7-10 RM submaximal strength test in healthy young adult males. *Journal of Exercise Physiology, 5*(3), 54-59.

Donnelly, D.V., Berg, W.P., & Fiske, D.M. (2006). The effect of the direction of gaze on the kinematics of the squat exercise. *The Journal of Strength & Conditioning Research, 20*(1), 145-150.

Drinkwater, E.J., Moore, N.R., & Bird, S.P. (2012). Effects of changing from full range of motion to partial range of motion on squat kinetics. *The Journal of Strength & Conditioning Research, 26*(4), 890-896.

Duchateau, J., Semmler, J.G., & Enoka, R.M. (2006). Training adaptations in the behavior of human motor units. *Journal of Applied Physiology, 101*(6), 1766-1775.

Epley, B. (1995). *Poundage chart: Boyd Epley workout*. Lincoln: University of Nebrask.

Escamilla, R.F. (2001). Knee biomechanics of the dynamic squat exercise. *Medicine & Science in Sports & Exercise, 33*(1), 127-141.

Escamilla, R.F., Fleisig, G.S., Lowry, T.M., Barrentine, S.W., & Andrews, J.R. (2001). A three-dimensional biomechanical analysis of the squat during varying stance widths. *Medicine & Science in Sports & Exercise, 33*(6), 984-998.

Fisher, J., Steele, J., Bruce-Low, S., & Smith, D. (2011). Evidence-based resistance training recommendations. *Medicina Sportiva*, *15*(3), 147-162

Fleck, S.J., & Kraemer, W.J. (2004). *Designing Resistance Training Programs* (3rd ed.). Champaign, IL: Human Kinetics Publishers.

Folland, J.P., & Williams, A.G. (2007). Morphological and neurological contributions to increased strength. *Sports Medicine, 37*(2), 145-168.

Garnacho-Castaño, M.V., López-Lastra, S., & Maté-Muñoz, J.L. (2015). Reliability and validity assessment of a linear position transducer. *Journal of Sports Science & Medicine, 14*(1), 128.

Gioftsos, G., Arvanitidis, M., Tsimouris, D., Kanellopoulos, A., Paras, G., Trigkas, P., & Sakellari, V. (2016). EMG activity of the serratus anterior and trapezius muscles during the different phases of the push-up plus exercise on different support surfaces and different hand positions*. Journal of Physical Therapy Science, 28*(7), 2114-2118.

González-Badillo, J.J., Gorostiaga, E.M., Arellano, R., & Izquierdo, M. (2005). Moderate resistance training volume produces more favorable strength gains than high or low volumes during a short-term training cycle. *The Journal of Strength & Conditioning Research, 19*(3), 689-697.

Granacher, U., Lesinski, M., Büsch, D., Muehlbauer, T., Prieske, O., Puta, C., Gollhofer, A., & Behm, D.G. (2016). Effects of resistance training in youth athletes on muscular fitness and athletic performance: a conceptual model for long-term athlete development. *Frontiers in Physiology, 7,* 164*.*

Gregory, C.M., & Bickel, C.S. (2005). Recruitment patterns in human skeletal muscle during electrical stimulation. *Physical Therapy, 85*(4), 358-364.

Gullett, J.C., Tillman, M.D., Gutierrez, G.M., & Chow, J.W. (2008). A biomechanical comparison of back and front squats in healthy trained individuals. *Journal of Strength & Conditioning Research, 23*(1), 284-292.

Gurney, A.B., Mermier, C., LaPlante, M., Majumdar, A., O'neill, K., Shewman, T., & Gurney, J.G. (2016). Shoulder electromyography measurements during activities of daily living and routine rehabilitation exercises*. Journal of Orthopaedic & Sports Physical Therapy, 46*(5), 375-383.

Haff, G.G., & Triplett, N.T. (2015). *Essentials of Strength Training and Conditioning 4th Edition*. New York: Human Kinetics.

Häkkinen, K., Kraemer, W.J., Pakarinen, A., Tripleltt-Mcbride, T., Mcbride, J. M., Häkkinen, A. & Newton, R.U. (2002). Effects of heavy resistance/power training on maximal strength, muscle morphology, and hormonal response patterns in 60-75-year-old men and women. *CanadianJournal of Applied Physiology, 27*(3), 213-231.

Hansen, K.T., Cronin, J.B., & Newton, M.J. (2011). The reliability of linear position transducer and force plate measurement of explosive force–time variables during a loaded jump squat in elite athletes. *The Journal of Strength & Conditioning Research, 25*(5), 1447-1456.

Hodson-Tole, E.F., & Wakeling, J.M. (2009). Motor unit recruitment for dynamic tasks: current understanding and future directions. *Journal of Comparative Physiology B,*179(1), 57-66.

Hori, N., Newton, R.U., Nosaka, K., & McGuigan, M.R. (2006). Comparison of different methods of determining power output in weightlifting exercises. *Strength & Conditioning Journal, 28*(2), 34-40.

Hug, F. (2011). Can muscle coordination be precisely studied by surface electromyography? *Journal of electromyography & kinesiology, 21*(1), 1-12.

Ibrahim, A.F.T., Gannapathy, V.R., Chong, L.W., & Isa, I.S.M. (2016). Analysis of Electromyography (EMG) Signal for Human Arm Muscle: A Review. *In Advanced Computer & Communication Engineering Technology* (pp. 567-575). Springer, Cham.

Kawamori, N., & Haff, G.G. (2004). The optimal training load for the development of muscular power. *The Journal of Strength & Conditioning Research, 18*(3), 675-684.

Kraemer, W.J., & Ratamess, N.A. (2004). Fundamentals of resistance training: progression and exercise prescription. *Medicine & Science in Sports & Exercise, 36*(4), 674-688.

Kraemer, W.J., Dziados J.E., Marchitelli L.J., Gordon S.E., Harman E.A., Mello R., Fleck S.J., Frykman P.N & Triplett N.T. (1993). Effects of different heavy-resistance protocols on plasma beta-endorphin concentrations. *Journal of Applied Physiology, 74*(1), 450-459.

Landers, J. (1985) Maximums Based on Reps. *National Strength & Conditioning Association Journal, 6*, 60-61.

Lee, H., Jung, M., Lee, K.K., & Lee, S.H. (2017). A 3D Human-Machine Integrated Design and Analysis Framework for Squat Exercises with a Smith Machine. *Sensors, 17*(2), 299.

Levinger, I., Goodman, C., Hare, D.L., Jerums, G., Toia, D., & Selig, S. (2009). The reliability of the 1RM strength test for untrained middle-aged individuals. *Journal of Science & Medicine in Sport, 12*(2), 310-316.

Lin, J., & Chen, T (2012). Diversity of strength training methods: A theoretical approach. *Strength & Conditioning Journal, 34*(2), 42-49.

Lombardi, V.P. (1989). *Beginning weight training: the safe and effective way*. William C Brown Pub.

Maddigan, M.E., Button, D.C., & Behm, D.G. (2014). Lower-limb and trunk muscle activation with back squats and weighted sled apparatus. *The Journal of Strength & Conditioning Research, 28*(12), 3346-3353.

Mayhew, J.L., J. Barnett, D. Schutter, & M.G. Bemben. (1995). Repetitions to predict 1RM in three upper body exercises. *The Journal of Strength & Conditioning Research,* 9(4), 283.

McMaster, D.T., Gill, N., Cronin, J., & McGuigan, M. (2014). A brief review of strength and ballistic assessment methodologies in sport. *Sports Medicine, 44*(5), 603.

Mitchell, C.J., Churchward-Venne, T.A., Bellamy, L., Parise, G., Baker, S.K., & Phillips, S.M. (2013). Muscular and systemic correlates of resistance training-induced muscle hypertrophy. *PloS One, 8*(10), e78636.

Naclerio, F.J., Jiménez, A., Alvar, B.A., & Peterson, M.D. (2009). Assessing strength and power in resistance training. *Journal of Human Sport & Exercise, 4*(II).

Newton, R.U., & Dugan, E. (2002). Application of Strength Diagnosis. *Strength & Conditioning Journal, 24*(5), 50-59.

Newton, R.U., Murphy, A.J., Humphries, B.J., Wilson, G.J., Kraemer, W.J., & Häkkinen, K. (1997). Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European Journal of Applied Physiology & Occupational Physiology, 75*(4), 333-342.

Niewiadomski, W., Laskowska, D., Gąsiorowska, A., Cybulski, G., Strasz, A., & Langfort, J. (2008). Determination and prediction of one repetition maximum (1RM): Safety considerations. *Jornal of Human Kinetics, 19*(1), 109-120.

O'Connor, B., Simmons, J., & O'Shea, P. (1989). *Weight Training Today*. St. Paul, MN: West Publishers,

Padulo J, Migliaccio GM, Ardigò LP, Leban B, Cosso M, Samozino P. Lower limb force, velocity, power capabilities during leg press and squat movements. *International Journal of Sport Medicine* [Epub ahead of print]

Padulo, J., Laffaye, G., Chaouachi, A., & Chamari, K. (2015). Bench press exercise: the key points. *The Journal of Sports Medicine & Physical Fitness, 55*(6), 604-608.

Padulo, J., Mignogna, P., Mignardi, S., Tonni, F., & D'ottavio, S. (2012). Effect of different pushing speeds on bench press. *International Journal of Sports Medicine, 33*(05), 376-380.

Padulo, J., Tiloca, A., Powell, D., Granatelli, G., Bianco, A., & Paoli, A. (2013). EMG amplitude of the biceps femoris during jumping compared to landing movements. *Springerplus, 2*(1), 520.

Paoli, A., Marcolin, G., & Petrone, N. (2009). The effect of stance width on the electromyographical activity of eight superficial thigh muscles during back squat with different bar loads. *The Journal of Strength & Conditioning Research, 23*(1), 246-250.

Picerno, P., Iannetta, D., Comotto, S., Donati, M., Pecoraro, F., Zok, M., ... & Patrizio, F. (2016). 1RM prediction: a novel methodology based on the force–velocity and load–velocity relationships. *European Journal of Applied Physiology*, *116*(10), 2035-2043.

Rahmani, A., Samozino, P., Morin, J.B., & Morel, B. (2017). A Simple Method for Assessing Upper Limb Force-Velocity Profile in Bench Press. *International Journal of Sports Physiology & Performance,* 1-23.

Rhea, M.R., Alvar, B.A., Ball, S.D., & Burkett, L.N. (2002). Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *The Journal of Strength & Conditioning Research*, *16*(4), 525-529.

Rønnestad, B.R. (2004). Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *The Journal of Strength & Conditioning Research, 18*(4), 839-845.

Rønnestad, B.R., Egeland, W., Kvamme, N.H., & Refsnes, P.E. (2007). Dissimilar effects of one-and three-set strength training on strength and muscle mass gains in upper and lower body in untrained subjects. *The Journal of Strength & Conditioning Research, 21*(1), 157-163.

Sakamoto, A., Sinclair, P., & Naito, H. (2017). Thrust back: A new strategy for reducing concentric deceleration during power training*. Journal of Science and Medicine in Sport, 20*, e116.

Samani, A., Srinivasan, D., Mathiassen, S.E., & Madeleine, P. (2016). Variability in patterns of muscular activity during a fatiguing repetitive task. In *Ninth International Conference on the Prevention of Work-Related Musculoskeletal Disorders (PREMUS), June 20-23, 2016, Toronto, Canada*.

Samozino, P., Morin, J.B., Hintzy, F., & Belli, A. (2008). A simple method for measuring force, velocity and power output during squat jump. *Journal of Biomechanics, 41*(14), 2940-2945.

Schick, E.E., Coburn, J.W., Brown, L.E., Judelson, D.A., Khamoui, A.V., Tran, T.T., & Uribe, B.P. (2010). A comparison of muscle activation between a Smith machine and free weight bench press. *The Journal of Strength & Conditioning Research, 24*(3), 779-784.

Schlumberger, A., Stec, J., & Schmidtbleicher, D. (2001). Single-vs. multiple-set strength training in women. *The Journal of Strength & Conditioning Research, 15*(3), 284-289.

Schoenfeld, B.J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *The Journal of Strength & Conditioning Research, 24*(10), 2857-2872.

Schoenfeld, B.J., Wilson, J.M., Lowery, R.P., & Krieger, J.W. (2016). Muscular adaptations in low-versus high-load resistance training: A meta-analysis. *European Journal of Sport Science, 16*(1), 1-10.

Schwanbeck, S., Chilibeck, P.D., & Binsted, G. (2009). A comparison of free weight squat to Smith machine squat using electromyography*. The Journal of Strength & Conditioning Research, 23*(9), 2588-2591.

Scott, C.B., Leighton, B.H., Ahearn, K.J., & McManus, J.J. (2011). Aerobic, anaerobic, and excess postexercise oxygen consumption energy expenditure of muscular endurance and strength: 1-set of bench press to muscular fatigue. *The Journal of Strength & Conditioning Research, 25*(4), 903-908.

Senna, G., Salles, B.F., Prestes, J., Mello, R.A., & Roberto, S. (2009). Influence of two different rest interval lengths in resistance training sessions for upper and lower body. *Journal of Sports Science & Medicine, 8(*2), 197-202.

Seo, D.I., Kim, E., Fahs, C.A., Rossow, L., Young, K., Ferguson, S.L., & Lee, M. K. (2012). Reliability of the one-repetition maximum test based on muscle group and gender. *Journal of Sports Science & Medicine, 11*(2), 221-225.

Sforzo, G.A., & Touey, P.R. (1996). Manipulating exercise order affects muscular performance during a resistance exercise training session. *The Journal of Strength & Conditioning Research, 10*(1), 20-24.

Sharma, T., Veer, K., & Agarwal, R. (2014). Non invasive technique based evaluation of electromyogram signals using statistical algorithm. *International Journal of Advanced Science and Technology*, 3, 1987-1991.

Simao, R., De Salles, B.F., Figueiredo, T., Dias, I., & Willardson, J. M. (2012). Exercise order in resistance training. *Sports Medicine, 42*(3), 251-265.

Slater, L.V., & Hart, J.M. (2017). Muscle activation patterns during different squat techniques. *The Journal of Strength & Conditioning Research, 31*(3), 667-676.

Tan, B. (1999). Manipulating Resistance Training Program Variables to Optimize Maximum Strength in Men: A Review. *The Journal of Strength & Conditioning Research, 13*(3), 289-304.

Vingren, J.L., Hill, D.W., Buddhadev, H., & Duplanty, A. (2013). Postresistance exercise ethanol ingestion and acute testosterone bioavailability. *Medicine & Science in Sports & Exercise, 45*(9), 1825-1832.

Wathen, D. (1994) Load assignment. In: Beachle, T.R., (ed.). *Essentials of strength training and conditioning.* Champaign, IL: Human Kinetics; 435-439.

Weiss, T., Kreitinger, J., Wilde, H., Wiora, C., Steege, M., Dalleck, L., & Janot, J. (2010). Effect of functional resistance training on muscular fitness outcomes in young adults. *Journal of Exercise Science & Fitness, 8*(2), 113-122.

Whisenant, M.J., Panton, L.B., East, W.B., & Broeder, C.E. (2003). Validation of submaximal prediction equations for the 1 repetition maximum bench press test on a group of collegiate football players. *The Journal of Strength & Conditioning Research, 17*(2), 221-227.

Whyte, G. (Ed.). (2006). The physiology of training. Elsevier Health Sciences.

Wilson, G.J., Murphy, A.J., & Giorgi, A. (1996). Weight and plyometric training: effects on eccentric and concentric force production. *Canadian Journal of Applied Physiology, 21*(4), 301-315.
Yavuz, H.U., Erdağ, D., Amca, A.M., & Aritan, S. (2015). Kinematic and EMG activities during front and back squat variations in maximum loads. *Journal of Sports Sciences, 33*(10), 1058-1066.
Zelber-Sagi, S., Buch, A., Yeshua, H., Vaisman, N., Webb, M., Harari, G., ... & Santo, E. (2014). Effect of resistance training on non-alcoholic fatty-liver disease a randomized-clinical trial. *World Journal of Gastroenterology, 20*(15), 4382 4392.
*** ACSM (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine & Science in Sports & Exercise*, *41*, 687–708.

SMITH MAŠINA: KLJUČNE TOČKE

Sažetak
Tijekom protekla dva desetljeća znanstvenici, treneri, terapeutski stručnjaci i drugi stručnjaci koriste Smith mašinu (SM) kako bi poboljšali snagu i jakost mišića donjeg dijela tijela. Pregledom literature, položaj šipke, opterećenje, volumen treninga (ponavljanja i setovi), oporavak (vrijeme odmora), ispoljena snaga, mišićni rad i maksimalno ponavljanje (1-RM) su karakteristike koje opisuju SM, i prikazane su kao varijable na kojima je usmjerena periodizacija programa u treningu s otporom. Cilj ovog kratkog pregleda jest pružiti relevantna znanstvena znanja i korisne informacije za kondicijske trenere, kao i za sve ostale osobe uključene u sportski ili terapeutski rad. Ovaj kratki pregled pruža uvid u nekoliko preporuka o ključnim točkama, čvrsto utemeljenih na relevantnoj literaturi.

Ključne riječi*: vanjsko opterećenje, izotonične vježbe, višezglobne vježbe, mišićna snaga, mišićna jakost.*

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