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PREDICTION OF ONE-REPETITION MAXIMUM AND THE LOAD CORRESPONDING TO 1M·S^{-1} IN THE FULL SQUAT EXERCISE FROM OTHER MORE FUNCTIONAL STRENGTH EXERCISES TO FACILITATE RESISTANCE TRAINING GUIDANCE

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Abstract

Mean propulsive velocity and 1 repetition maximum (1RM) are considered the gold-standard variables for muscle strength assessment and training monitoring. Athletic performance is often assessed using vertical jump tests because they are thought to be a good predictor of sprinting strength. The aim of the current research was to analyze the relationships between countermovement jump (CMJ) and the load corresponding to 20cm (CMJ20cm) with the load corresponding to $1 m·s^{-1}$ (V1load) and 1RM in the squat exercise. Twenty-two male regional runners took part in this study. Runners performed the CMJ, loaded CMJ, as well as the full squat [1RM and submaximal load associated with $1 m·s^{-1}$ mean propulsive velocity (V1load)]. *Moderate* relationships were found between CMJ with V1load and 1RM ($r = 0.47$ and 0.48, respectively), and *very large* relationships between CMJ20cm with V1load and 1RM ($r = 0.806$ and 0.81, respectively). In conclusion, CMJ20cm robustly predict V1load and 1RM. This would be of practical and clinical interest to evaluate, monitor and re-adjust the training-load intensities of the lower-limb strength training more frequently.

Key words: CMJ, CMJ20cm, V1load, 1RM, resistance training, movement velocity, sprinters, strength testing.

Resumen

La velocidad de propulsión media y 1 repetición máxima (1RM) se consideran las variables de referencia para la evaluación de la fuerza muscular y el seguimiento del entrenamiento. El rendimiento atlético a menudo se evalúa mediante pruebas de salto vertical porque se cree que son un buen predictor de la fuerza del sprint. El objetivo de la presente investigación fue analizar las relaciones entre el salto con contramovimiento (CMJ) y la carga correspondiente a 20cm (CMJ20cm) con la carga correspondiente a $1 m·s^{-1}$ (V1carga) y 1RM en el ejercicio de sentadilla. En este estudio participaron veintidós corredores regionales masculinos, realizando CMJ, CMJ cargado, así como sentadilla completa [1RM y la carga submaxima asociada con $1 m·s^{-1}$ de velocidad de propulsión media (V1carga)]. Se encontraron relaciones moderadas entre CMJ con V1carga y 1RM ($r = 0{,}47$ y 0,48, respectivamente), y relaciones muy grandes entre CMJ20cm con V1carga y 1RM ($r = 0{,}806$ y 0,81, respectivamente). En conclusión, CMJ20cm es fuertemente capaz de predecir la carga V1carga y la 1RM. Esto sería de interés práctico y clínico para evaluar, monitorear y re-ajustar las intensidades de la carga de entrenamiento del entrenamiento de fuerza de las extremidades inferiores con mayor frecuencia.

Palabras clave: CMJ, CMJ20cm, V1carga, 1RM, entrenamiento de fuerza, velocidad de movimiento, sprinters, test de fuerza.

Laburpena

Batez besteko propultsio-abiadura eta errepikapen maximo bat (1RM) hartzen dira kontuan muskulu-indarra ebaluatzeko eta entrenamenduaren segimendua egiteko erreferentziazko aldagaiak. Atletismoko errendimendua, askotan, jauzi bertikaleko proben bidez ebaluatzen da, esprintaren indarraren iragarpen ona direla uste baita. Ikerketa honen helburua kontramugimenduzko jauziaren (CMJ) eta 20 cm-ko kargaren (CMJ20 cm) eta $1m\cdot s^{-1}$-i (V1karga) eta 1RM-ri dagokien kargaren arteko erlazioak aztertzea izan zen. Azterketa honetan, maila erregionaleko hogeita bi korrikalari gizonezko parte hartu zuten eta hiru indar ariketa burutu ziren: CMJ, kargatutako CMJ, eta sentadilla osoa [1RM eta $1m\cdot s^{-1}$-i dagokion batez besteko propultsio-abiadura karga submaximoa (V1karga)]. Neurrizko harremanak aurkitu ziren CMJ eta V1karga eta 1RM-ren artean (r = 0,47 eta 0,48, hurrenez hurren) eta erlazio oso handiak CMJ20cm eta V1karga eta 1RM-ren artean (r = 0,806 eta 0,81, hurrenez hurren). Beraz, CMJ20cm ariketa funtzionalak zehaztasun sendo batekin aurresan dezake V1karga eta 1RM. Horrek interes praktiko eta klinikoa izango luke beheko gorputz-adarretako indar-entrenamenduaren entrenamendu-kargaren intentsitateak maizago ebaluatzeko, monitorizatzeko eta doitzeko.

Gako-hitzak: CMJ, CMJ20cm, V1karga, 1RM, indar entrenamendua, mugimendu abiadura, sprinterrak, indar testa.

Introduction

Most frequent lower-limb strength exercises performed by 200m runners and other athletes during resistance training

Sprint specific type exercise selection depends entirely on the personal preference of the coach, however, to build a solid foundation of strength, compound exercises like squat cannot be left aside. (Haugen, Seiler, Sandbakk, & Tønnessen, 2019). The full squat is one of the most efficient and useful exercises in the strength training community to improve lower-limb strength, avoid injuries and improve athletic capacity (Hartmann, Wirth & Klusemann, 2013). The squat exercise is a closed kinetic chain exercise (Escamilla et al., 1998). In closed kinetic chain exercises, it means that either palms or soles are in touch with an immovable object, such as the ground or a bar. In the case of the squat, feet remain motionless in the ground, and the force is produced by counteracting the gravity force of one's body weight or external load like barbells (Ellenbecker & Davies, 2001). Apart from all the muscle groups that take part (quadriceps, hamstrings, gluteus maximus, triceps surae and erector spinae), this exercise demands a coordinated multi-joint (spine, hip, knee and ankle) movement (Robertson, Wilson & Pierre, 2008).

The full squat has been used lately by physiotherapists in rehabilitation environments, because it is thought to be a functional exercise for everyday life activities and sporting movements

(Schoenfeld, 2010). When the technique is properly taught, loads and learning progression is adequate, the squat has been proved to be a safe and healthy exercise for soft tissue, muscle and bone strengthening (Panariello, Backus & Parker, 1994). There are different ways of performing a squat, but the main variables are the bar position (high bar, low bar, front squat) and the squatting depth. Many studies have proved lower-body squat strength training transfers into gains when it comes to athletic performance in short length activities such as sprinting and vertical jumping, especially when motor units are recruited (Hartmann et al., 2012). For safety and standardization reasons, a smith machine is usually employed. The Smith machine has many downsides, for instance, you are not engaging your stabilizer muscles, it is not a natural movement, because you are lifting the bar only in a straight line and a barbell normally travels not only up and down but also forward and back. However, the primary benefit of a Smith machine is also its biggest disadvantage, and that is balance. Unlike a regular free-weight barbell, where your stabilizers (erector spinae, rectus abdominis, internal and external obliques, abdominal) need to be coactivated, the Smith machine balances for you (Anderson & Behm, 2005). This makes it good for newbies and for those with injuries. When you erase the element of balance, athletes do not have to pay attention that much to the technique so they can manifest their fullest potential in the exercise.

Traditional measurement of strength in full-squat exercise. The one-repetition maximum

Traditionally, measuring one-repetition maximum (1RM) squat was considered as the "gold standard" for assessing the lower limb strength capacity of individuals in non-laboratory environments. Despite being simple, time effective, inexpensive and in many cases reliable, various concerns have been raised about this testing protocol (Seo et al., 2012).

It has been suggested that lifters lacking experience should not perform a 1RM strength test, just because lifting the maximal weight for only one repetition without proper preparation and correct technique may induce a high risk of injury and large amounts of soreness detrimental for strength gains. For that reason, monitoring 1RM on a weekly basis is not recommended and it makes it hard to track the progress in maximal strength of the athletes (Braith, Graves, Leggett, & Pollock, 1993). Also, athletes do not feel the same way every day and manifesting your greatest drive when your coach asks you to, is often difficult. In beginners, the real value of 1RM can change relatively quickly after a few sessions due to the rapid neural adaptations, and mainly, due to improvements in the technique of the mentioned strength exercise. In contrast, more experienced athletes can stay under their real RM for longer periods. In the following figure we can see how in early stages of strength training, most of the short term adaptations are coming from the nervous system (Sale, 1998).

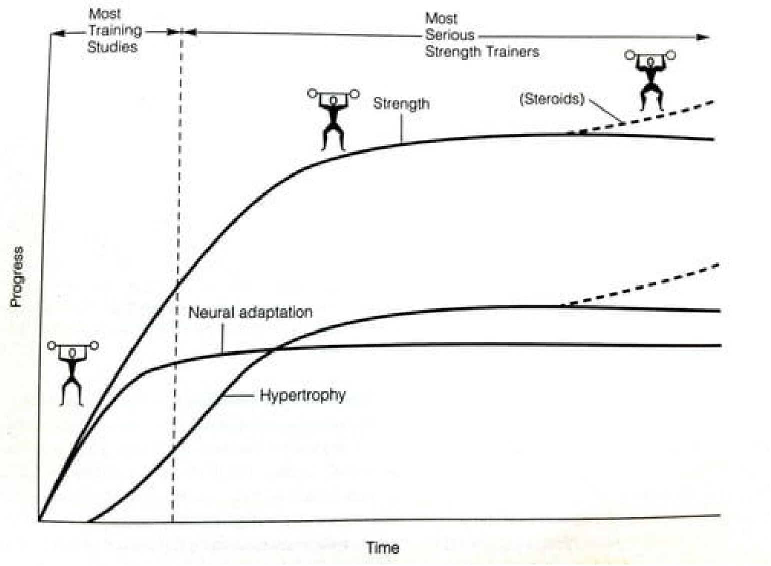

Figure 1: The relative roles of neural and muscular adaptation to strength training.

Note. Adapted from: "Neural adaptation to resistance training." from Sale D. G, 1988, *Medicine and science in sports and exercise*, *20*(5 Suppl), S135–S145.

Moreover, if athletes make their long term programming based on their 1RM that had been measured before starting the program, by the time they reach, for instance, the 12th session, the athlete's 1RM might have changed considerably. An example of this is illustrated in the next figure (Figure 2). An athlete's mean propulsive velocity and his estimated 1RM was monitored during 12 strength training sessions. It is observed that the gap between the prescribed %1RM (blue line) and the real measured %1RM (red line) got wider during the training program. A noticeably difference between the prescribed and performed strength training was observable. This shows the great importance of re-testing or finding alternative simple ways of measuring the real internal effort of the athletes during their resistance trainings.

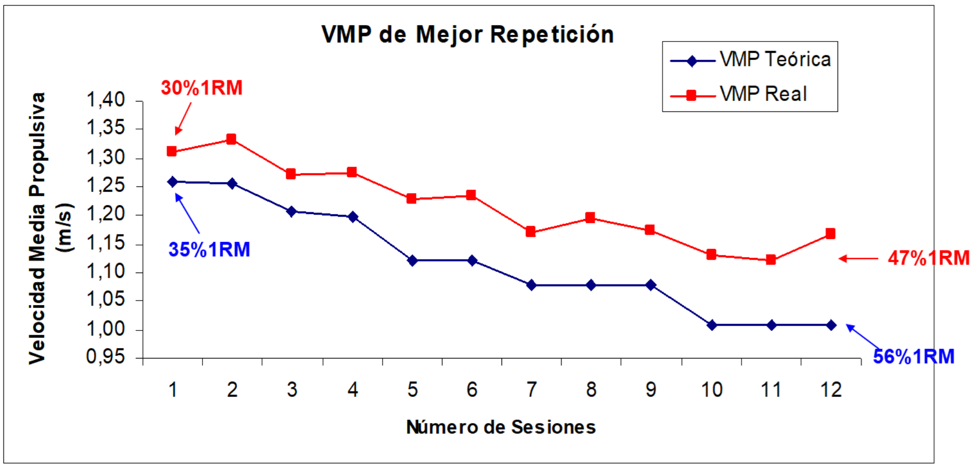

Figure 2: Prescribed mean propulsive velocity (i.e. %1RM) (blue line) and monitored mean propulsive velocity (i.e. trained %1RM) (red line) during 12 sessions (6-8 weeks) in a representative athlete.

The concept of movement velocity and its relationship with the one-repetition maximum

The kinematics and kinetics related to resistance training are believed to be powerful stimuli for neuromuscular adaptations to happen (Crewther, Cronin & Keogh, 2005). Lately, many of the researches are placing their interest in that direction (Conceição, Fernandes, Lewis, Gonzaléz-Badillo, & Jimenéz-Reyes, 2016). Monitoring movement velocity is crucial because muscle fiber recruitment largely depends on the speed at which loads are lifted (González-Badillo, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & Pareja-Blanco, 2014). Different data shows that regardless of sport discipline, athletes optimum mean propulsive power is achieved when the movement velocity is close to 1.0 $m.s^{-1}$ during the full-squat exercise and at a jump height close to 20cm (20.47 ± 1.42 cm) in the loaded countermovement jump exercise (Loturco I. et al.,2015). It was found that the relative load (%1RM) and the mean vertical bar velocity had a really close relationship in the squat exercise and many other strength exercises (Conceição et al., 2016). Therefore, velocity-based resistance training is key to monitor training loads (González-Badillo et al., 2015). There are different ways of monitoring velocity, but linear transducers are the most frequently used. Linear velocity transducers have been proven to be more precise than any other device such as linear position transducers, optoelectronic camera based systems (OEC), smartphones video-based systems and accelerometers (Courel-Ibáñez, 2019).

Consequently, the mean propulsive velocity is considered the current gold standard measure to guide resistance training. It is the steadiest variable for muscle strength assessment and training monitoring in order to objectively quantify the strength testing and/or training-induced strength adaptations, either for health or sport performance outcomes. Submaximal mean propulsive velocity, such as the load corresponding to $1m \cdot s^{-1}$ (V1load), allows coaches to assess, prescribe and monitor resistance training without having to perform 1 repetition maximum (1RM) test avoiding unnecessary risks and efforts associated with maximum testing. Sophisticated instruments, however, are usually required to measure V1load. There are less expensive alternatives like “The My Lift” smartphone app, and their popularity is increasing dramatically. However, there are some validity and reliability doubts concerning these new apps to measure movement velocity during strength training (Martínez-Cava et al,. 2020).

Countermovement jump and Countermovement jump load corresponding to 20cm

The counter-movement jump (CMJ) is a test to assess an athlete’s explosive lower-body power (Young, 1995) and it is one of most widely used indirect tests by strength training coaches to measure the power out of the lower body limbs (Dias et al., 2011). This test can be performed without, or with little, instrumentation. It is of great interest to test the CMJ on 200m runners, because this test has been positively correlated with sprint performances (Markstrom & Olsson, 2013) and relative strength during dynamic 1RM squat and power clean strength exercises (Nuzzo, Anning, &

Scharfenberg, 2011). This means that the higher they jump in this test, generally, the better they will perform in sprints and 1RM test such as the back squat exercise. The CMJ is therefore a potential indicator of 1RM in sprint athletes. This, nevertheless, as far as we are concerned, has not been yet investigated.

Another important strength exercise for sprint athletes is the CMJ loaded (CMJloaded). In this exercise, usually the load corresponding to the jump of 20cm (CMJ20cm) concurs with the maximum power load in this test (Jimenez-Reyes, Cuadrado-Peñafiel & Gonzalez-Badillo, 2011). Baker, Nance and Moore (2001) discovered something similar when they found out that the load at which maximum power was achieved was 30-40%RM for men in the exercise of CMJloaded, which was close again to CMJ20cm. This makes this test a simple test to assess lower-limb muscle strength in strength-trained athletes like sprinters. This has a lot of practical implications because this indicator allows coaches and trainers to assess the current performance of athletes in an easier manner to quantify and monitor training loads. However, to the best of the author's knowledge, no study has compared the validity of the CMJ and CMJ20cm in comparison to the squat V1load and 1RM in the full squat exercise in well-trained athletes, like 200 meter runners.

Aims of the study

Therefore, the aim of the current research was to analyze the relationships, if any, between the functional measures of CMJ and CMJ20cm with V1load and 1RM in the squat exercise in 200m runners. The use of the equations to predict V1load and 1RM in the full squat exercise could be of great practical importance. Being able to objectively guide resistance training without the need of sophisticated apparatus would be of particular interest to coaches and strength and physical conditioning practitioners for the benefit of their clients, patients, or athletes.

Methods

Participants

Twenty-two male regional runners (age 21.2 ± 3.1 years, body mass 70.8 ± 5.7 kg, height 180.1 ± 4.7 cm, body fat 7.1±1.7%) volunteered to take part in this study. Participants belonged to 2 sport performance centers of 2 different autonomous regions of Spain. Participants were national level athletes, most of them competing in both 200m and 400m races throughout both the competitive indoor and outdoor seasons. Best performance time records of the year previous to the study ranged between 21.69 to 24.45 s over 200m and 48.35 to 53.98 over 400m. Mean running time of a simulated 200m competition during the study period was 23.67 ± 0.70 s. Taking into account that the minimum mark to classify in the Spanish National Championship in male athletes currently is 23.40s in under-18 (RFEA, 2020), this means that most of the participants who took part in the study presented a decent national-level of performance and training experience.

After being informed of the purpose and testing procedures of the study, participants signed a written informed consent form prior to participation. Procedures were approved by the local Institutional Review Committee (A500001-A5410-2299-336102 and A50002-A5130-4809-336100) and the study was conducted in agreement with the guidelines established by the Declaration of Helsinki. Participants were not taking any performance enhancing drugs, medications or dietary supplements known to alter physical performance.

Study Design

The study was a cross-sectional study that analyzed the relationships of 3 lower-limb strength exercises aiming to estimate V1load and 1RM in the full squat exercise from other practical and easier resistance exercises. This would be of practical and clinical interest to evaluate, monitor and re-adjust the training-load intensities of the lower-limb strength training more frequently.

Testing Procedures and Materials

Data was collected during an inter-regional training camp of 2 different sport performance centers at Christmas break. Prior to the visit, participants were instructed to abstain from caffeine and stimulants for at least 2h and vigorous activity for ≥24 h before testing. Testing was performed in a laboratory setting in controlled atmospheric conditions (~20ºC, 38% humidity, 716 mmHg). Testing sessions were conducted at the same time of day for all participants to control for circadian rhythm effects on neuromuscular performance (Pallares et al., 2015).

Prior to the strength testing, anthropometrical assessment was performed. Height and body mass were determined using a medical stadiometer and scale (Año Sayol, Barcelona, Spain) to a precision of 0.001 m and 0.01 kg, respectively. A skinfold-caliper accurate to 0.2 mm (Harpenden, British Indicators, West Sussex, UK) was used to measure the skinfold thickness by a trained kinanthropometry physician. The seven skinfold thicknesses (triceps, subscapular, suprailiac, abdominal, front thigh, pectoral and midaxilla) were summed to provide an index of subcutaneous adiposity. Body fat percentage was calculated as previously described (Jackson & Pollock, 1978).

Prior to the commencement of testing, participants performed a 15-min standardized warm-up that consisted of 5 min of stationary treadmill at a self-selected easy pace, then 3 min of hip mobility exercises, followed by 8 min of dynamic exercises (crossing, heel to butt, kick and clap, skipping, vert impulsion, russian) and finally, two 40m progressive sprints in a running-track. All participants carried out the warm up and subsequently the tests in the same order and criteria. Furthermore, every strength test was further complemented with a specific warm-up consisting of some progressive repetitions while ensuring good execution technique. After anthropometric measures were assessed, participants performed the tests in the same following order: 1) the unloaded CMJ, 2) CMJloaded and finally, 3) the full-squat exercise.

Countermovement jump and Countermovement jump loaded

Countermovement jump was performed. All participants completed six maximal CMJs with their hands on their hips and ≈90º knee flexion separated by two minute rest, following procedures published by Garcia-Ramos et al. (2020). The highest and lowest values were discarded, and the resulting average value was kept for further analysis (Pareja-Blanco et al., 2017).

Afterwards, CMJloaded with progressive incremental external loads was performed. Athletes started from the upright position with the knees and hips fully extended, stance approximately shoulder width apart and the olympic barbell resting across the back at the level of the acromion. The test consisted of jumping with an Olympic barbell leaning on the neck and shoulders, increasing the weight progressively by 10kg until reaching a jumping height of ≤18 cm. This height was used because if jumps were lower than that it would progressively decrease the reliability of the jump and it decreases the risk of injury (Morgan, 2019). The athletes were told to hold the barbell against their neck throughout the flight, preventing them from splitting up. Two jumps were done as a warm up with the first load that was going to be measured (the barbell, i.e. 10kg), they rested for 2 min and started the test. These instructions were based on a thesis about the influence of loading protocol on a weighted countermovement jump (Morgan, 2019).

For both CMJ unloaded and CMJloaded assessments, detailed instructions were given to the participants for a proper execution. During their time spent in the air, it was really important for the athletes to keep extension in the hip, knee, and ankle joints to prevent them from achieving extra flight time by flexing their knees (Glatthorn et al., 2011). The participant started from an upright standing position, and countermovement depth was set at 90 degrees. This is the depth the athletes dropped during the short “countermovement” or “pre-stretch” action before take-off. After the push off was done at maximal intended velocity, instructions were also given about jump displacement. It was also important that the athlete not only did jump as high as possible, but also attempted to land in the same position as they had previously taken off - as jumping forwards, backwards or sideways could have affected the test results (Klarova, 2000).

In the current study, an infrared timing system was used (Optojump; Microgate, Bolzano, Italy). This device is capable of calculating the jump to the nearest 0.1 cm from flight time. The displacement of the center of gravity during the flight was estimated from the jumping height (h), which was calculated using the recorded flight time with the following formula of Bosco, Luhtanen, and Komi (1983) that is, h = t2 x 1.22625, with h being the jump height in meters and t being the flight time of the jump in seconds. The CMJloaded test was done by progressively increasing the load by 10kg until a height smaller than 18cm was achieved. To determine the CMJ20cm, linear interpolation was used as described in Figure 3.

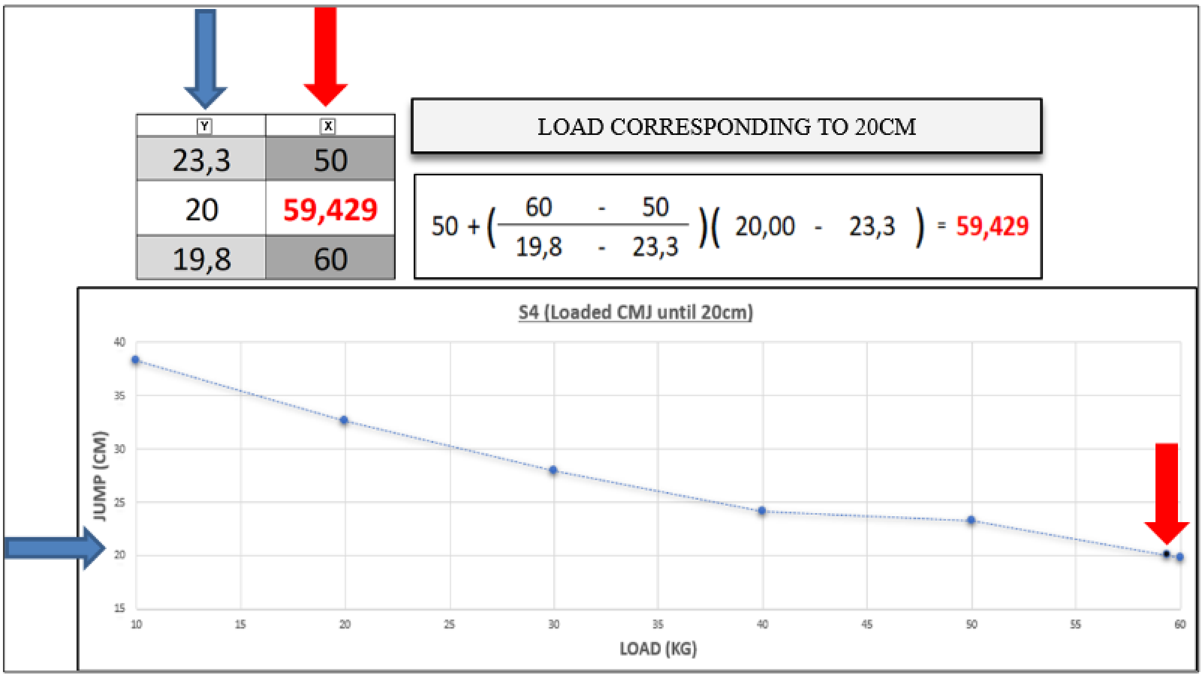

Figure 3: There are 3 graphics merged into this figure with data of a representative participant. The first two on top show the measurement of the load corresponding to 20cm by interpolating the closest loads (50kg and 60kg) and their respecting height (19.9 and 23.3 cm, respectively). On the bottom, the graphic shows the height reached with different loads (starting with 10kg) until the desired height is achieved. Red arrow indicated the calculated load corresponding to 20cm by means of the interpolation formula exposed on the top of the figure.

The Full Squat

To perform the full squat exercise, a Smith machine was used without any counterweight mechanism (Multipower Fitness Line, Peroga, Murcia, Spain) to ensure a smooth vertical displacement of the bar along a fixed pathway. A linear velocity transducer (T-Force System Version 3.60, Ergotech, Murcia, Spain) was used to measure the kinematics of every repetition and provided auditory and visual velocity feedback. The starting point was an upright position with the knees and hips fully extended, stance was shoulder-width with both feet placed flat on the ground in parallel or with a slight external rotation, maximum of 15° depending on the individual characteristics. All participants started descending in a uniform linear motion until breaking the parallel (tibia and femur creating 35-45° angle), and afterwards suddenly ascending back to the upright position without eliminating the contribution of the stretch-shortening cycle. As it is a high bar technique, the bar was placed on the upper part of the trapezius, grip was pronated and as closed as possible to keep the tension and avoid collapsing, gaze was straight for to protect the neck and the trunk was in a neutral spine position. A linear velocity transducer was attached to the bar to get the peak and the mean values of the following variables: force (N), velocity (m/s), and power (W). The transducer was fixed horizontally to the bar with a fastener and reported its vertical instantaneous velocity at a rate of 1,000 Hz. If a repetition failed the pre-established conditions, it had to be done again after a 3 min time off. The concentric phase was performed as fast as the participants could, without breaking proper form. To obtain a maximal effort for each repetition, verbal encouragement was provided. Initial load started at 27kg and progressively increased by 10kg (or in some cases 5kg) loads until the mean propulsive velocity was lower than 1.0 $m.s^{-1}$. The 1RM load was estimated from the individual load vs. mean propulsive linear relationships (Sánchez-Medina, Pallarés, Pérez, Morán-Navarro., & González-Badillo, 2017). All individual load vs. mean propulsive velocity relationships were r > 0.95. For the mean propulsive velocity, only the fastest repetition at each load was considered. The exact load corresponding to V1load was calculated using linear interpolation, as previously explained with the CMJ20cm. The velocities reported in this study represent the mean velocity of the propulsive phase of the fastest repetition of each load.

Statistical Analysis

Standard statistical methods were used to calculate means, standard deviations (SD) and coefficient of variation (CV). Data was analyzed using parametric statistics following confirmation of normality (Kolmogorov-Smirnov test) and homoscedasticity (Levene’s test). Linear regression analyses with Pearson’s product-moment correlation coefficients (r) were used to determine the direction and magnitude of the relationships between the variables of interest. The magnitudes of the correlations were interpreted as follows: 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; and 0.9, extremely large (Hopkins, Marshall, Batterham, & Hanin, 2009). The accuracy of each linear regression was evaluated using the standard error of the estimates (SEE) and the 95% confidence intervals (CI) for the slope. Analyses were performed using IBM SPSS Statistics 22 (IBM Corporation, Armonk, NY, USA). Significance was set at P<0.05. Descriptive statistics are reported as means (± SD).

Results

Countermovement jump, Countermovement jump loaded and Full-Squat results

The mean CMJ of the participants was 44.4 ± 3.5 cm, ranging from 37.4 to 50.18 cm. Figure 4 shows the individual mean CMJ of every participant in ascending order.

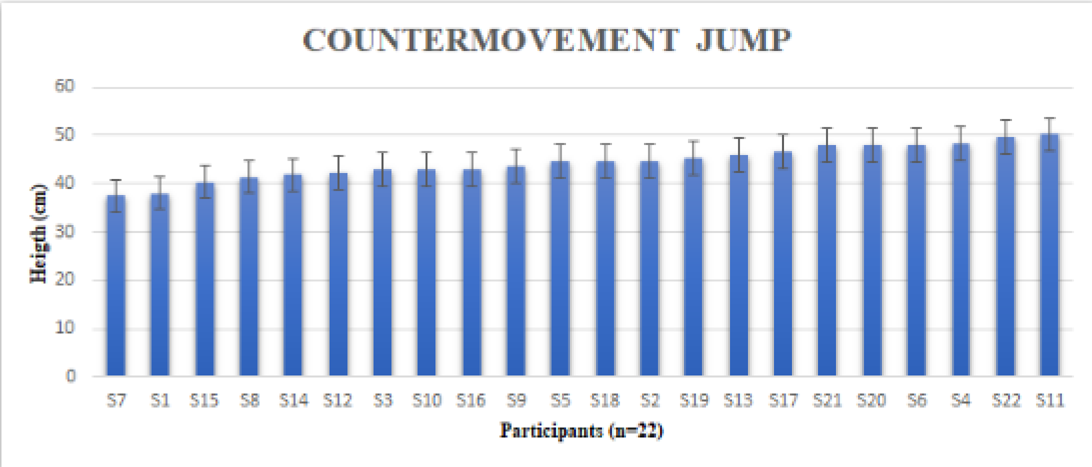

Figure 4: Individual mean heights of the CMJ vertical jump of all the 22 participants in ascending order. S: Subject

Figure 5 shows the mean (SD) values of the height of the vertical jumps for every load corresponding to the CMJloaded exercise. As shown in Figure 5 all participants were able to jump > 18cm in each of the first 4 loads. From the 40kg load on, instead, some participants jumped below 18 cm. On average, participants' CMJ20cm load was 45.8 ± 9.8 kg (ranging from 22.8 to 63.2 kg).

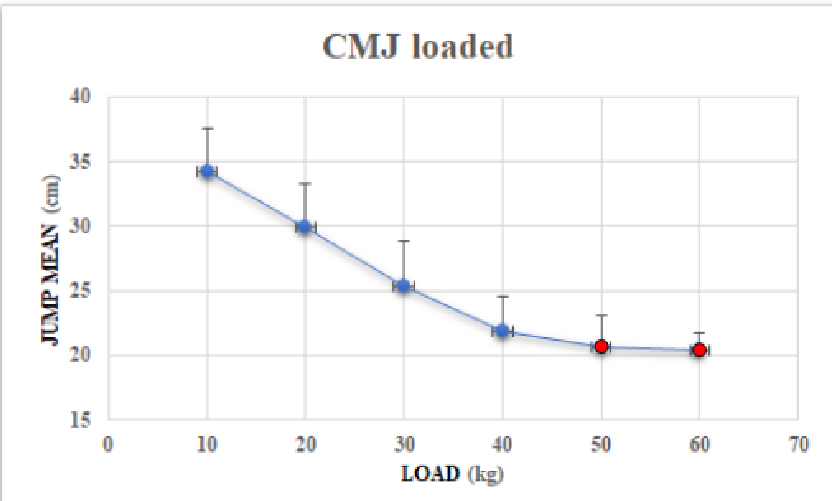

Figure 5: The mean height values (SD) of the jumps for every load corresponding to the CMJ loaded exercise. Filled blue circles indicated mean (SD) values of all participants (n = 22). Filled red circles indicated mean (SD) values of only the participants who attained the CMJ20cm above the 40kg load (n < 22).

Figure 6 illustrates determination of the V1laod in the full squat test on a representative participant. This figure displays 2 variables on the y-axis [“power” (W) in red and “velocity” (m/s) in blue] in relation to the load (kg) on the x-axis. Velocity decreases linearly as the load gets heavier. On the contrary, power increases exponentially. However, once it reaches a certain point this rule is no longer valid and power starts to fall. The point before the power starts to fall is usually very close to the V1load (Izquierdo, Häkkinen, Gonzalez-Badillo, Ibáñez, & Gorostiaga, 2002), as it can be noted in Figure 6. For velocity and power variables on the y-axis there is a linear equation and a polynomial equation, respectively. These equations can be used to estimate a particular variable for a certain load. Nevertheless, for the purposes of this research, linear interpolation was used to determine the V1load following previous procedures (Garcia-Tabar, Izquierdo, & Gorostiaga, 2017). On average, the mean values for the V1load were 61.5 ± 13.7 kg (ranging from 40 to 88 kg). Estimated mean 1RM in the full squat exercise using the individual velocity-load linear equations (e.g. individual linear regression illustrated in blue for S2 in the Figure 6) obtained with the encoder was 102.8 ± 21.2 (ranging from 67 to 145 kg).

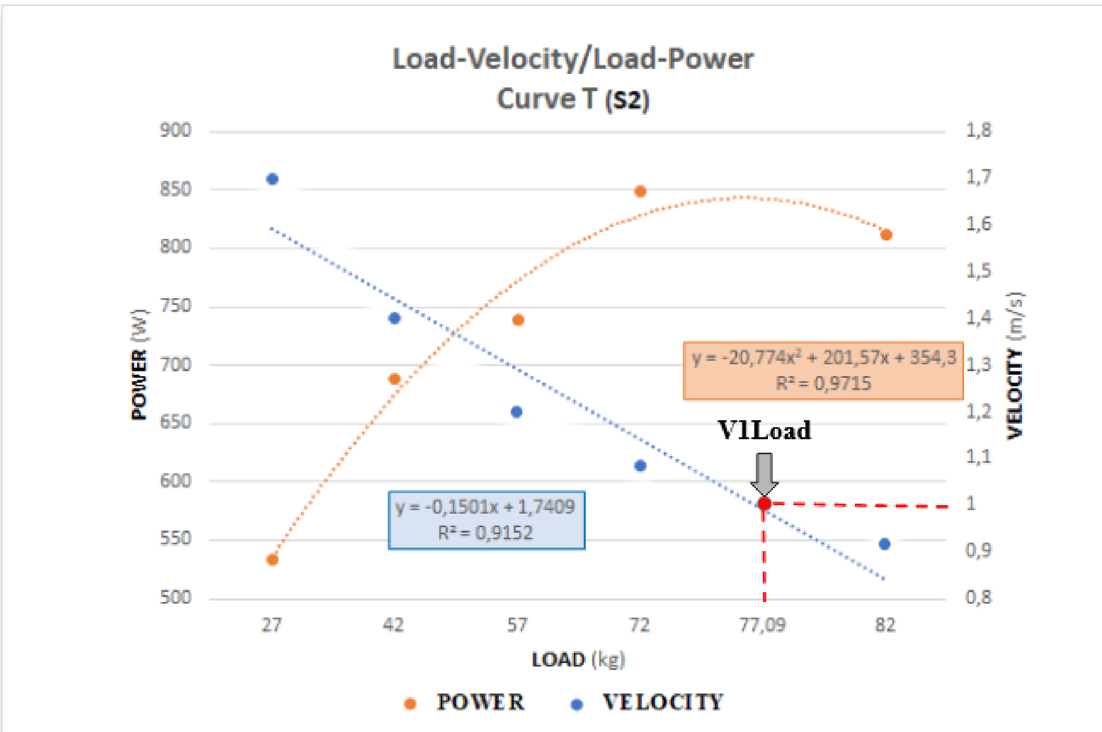

Figure 6: This graphic displays 2 variables on the y-axis [“power” (W) in red and “velocity” (m/s) in blue] in relation to the load (kg) on the x-axis taken from the full squat test on a representative participant from the sample (S2). V1load determination by means of linear interpolation is illustrated in red color.

Relationships between Countermovement jump, Countermovement jump loaded and Full-Squat

CMJ correlated *largely* (r = 0.66; P = 0.01; SEE = 2.69; 95% CI = 0.109 to 3.360) with CMJ20cm, with SEE being 5.9% of the mean. The individual data-points and the *large* linear relationship are illustrated in Figure 7.

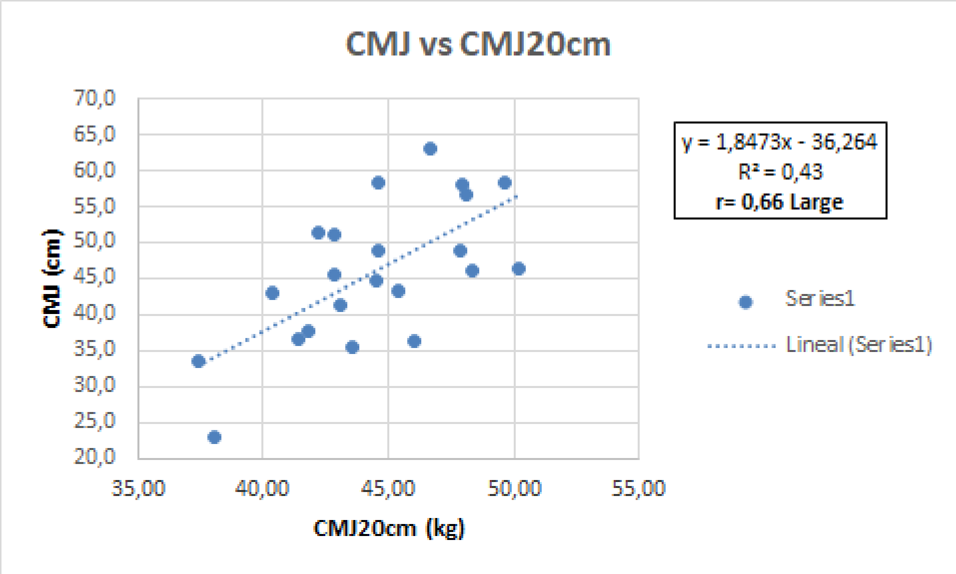

Figure 7: *Large* linear relationship (r = 0.66; P = 0.01; SEE = 2.69; 95% CI = 0.109 to 3.360) between the countermovement jump load corresponding to the jump of 20cm (CMJ20cm) and the unloaded countermovement jump (CMJ). CI, confidence interval; r, Pearson's product-moment correlation coefficients between estimated and measured values; P, probability value; SEE, standard error of estimate. Dashed line: Linear regression line.

Figure 8 depicts the relationships between CMJ and CMJ20load with the V1load and the 1RM obtained in the full squat exercise. CMJ *moderately* correlated with V1load (r = 0.47; P = 0.027; SEE = 12.375; 95% CI = 0.228 to 3.451) and 1RM (r = 0.485; P = 0.022; SEE = 19.037; 95%CI = 0.466 to 5.423), (Figure 8, **A** and **B**). CMJ20load was *very largely* correlated to V1load (r = 0.806; P = 0.000; SEE = 8.298; 95%CI = 0.739 to 1.509) determined in the squat exercise and 1RM (r = 0.81; P = 0.000; SEE = 12.744; 95%CI = 1.163 to 2.345), (Figure 8, **C** and **D**).

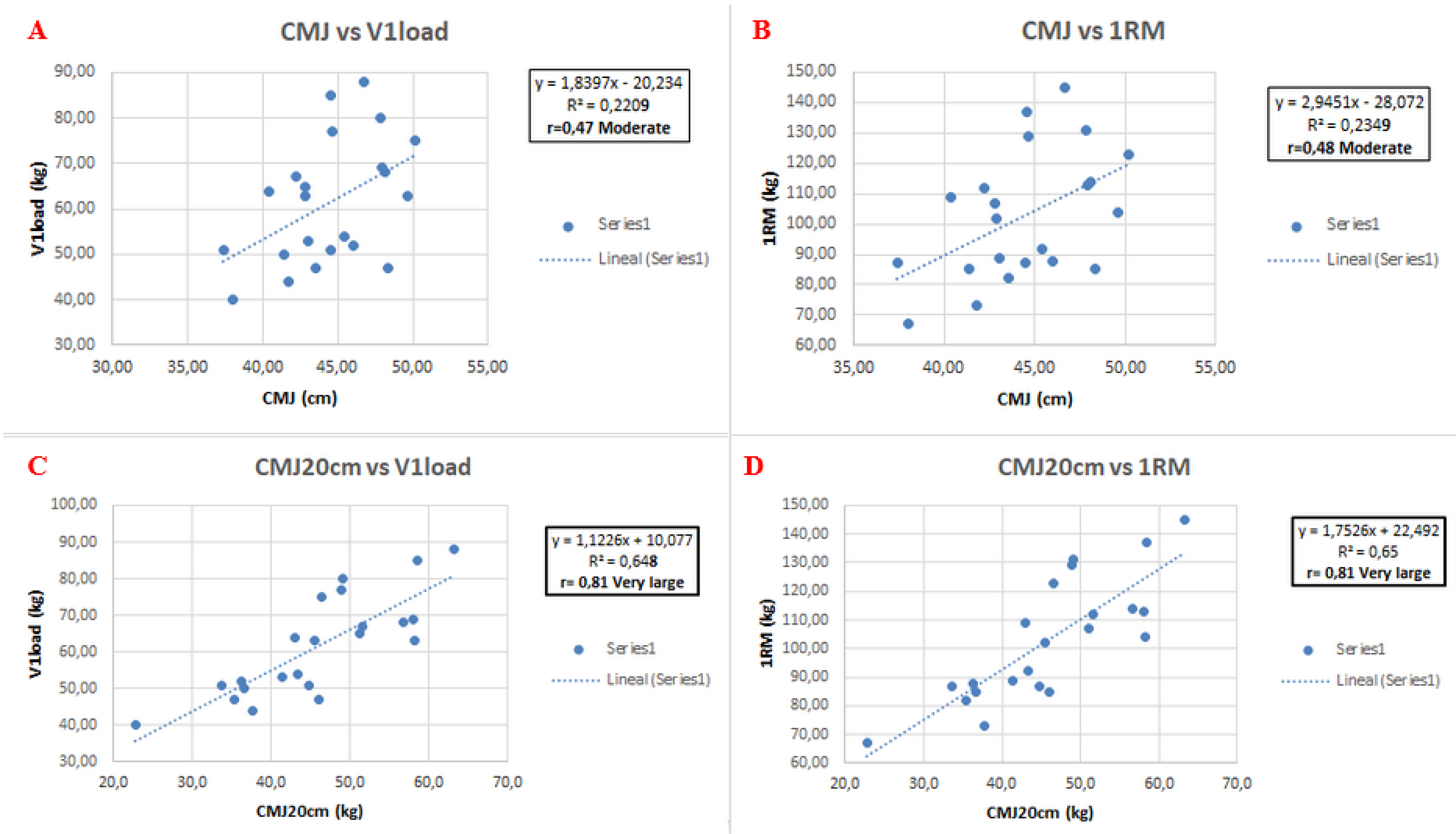

Figure 8: Individual data-points and linear significant ($p < 0.05$) relationships describing the correlations between CMJ with V1load (A) and 1RM (B), and CMJ20cm with V1load (C) and 1RM (D). CMJ., countermovement jump; CMJ20cm., the countermovement jump load corresponding to the jump of 20cm; V1load., the load corresponding to $1 m \cdot s^{-1}$; r, Pearson's product-moment correlation coefficients between estimated and measured values; 1RM., one repetition maximum.

Discussion

This study aimed to establish the relationships and equations, if pertinent, between 3 lower-limb strength exercises (the CMJ, the CMJloaded, and the full-squat exercises). These equations might allow coaches and sports science trainers a more time-efficient, cheaper, and relatively accurate way to estimate V1load / 1RM in the full-squat exercise from other more functional exercises. Moderate relationships were found between CMJ with V1load and 1RM (r = 0.47 and 0.48, respectively) with relatively large SEE (>12%). The load associated with 20cm in the loaded CMJ exercise was closely related to the V1load and 1RM variables in the full squat exercise (r = 0.806 and 0.810, respectively), with relatively low SEE (<12%). The CMJ does not appear to accurately estimate the V1load and 1RM variables of the full squat exercise. That is, in the real clinical training context, individual errors may be too large to accurately determine full squat velocity or maximal variables using the countermovement vertical jump. In contrast, due to the close relationship and relatively low estimation errors, the CMJ20cm variable can serve to estimate the V1load and 1RM of the full squat exercise quite accurately.

As far as the author is aware, this is the first study to compare the relationship between V1load with other more functional exercises. Jimenez-Reyes et al. (2016) took fifty trained male athletes and concluded that the load that maximizes power output in CMJ was always when reaching a jump height close to 20,1 ± 2,93 cm, 97,5 ± 1,63** (% of maximum power, **; p<0.01). Baker et al. (2011) found in a sample of competitive male rugby league players from the same football club that Pmax during jump squats are achieved at 48-63% of 1RM, higher resistances than previous recommendations (30-45% of 1RM). This gives a good rationale to investigate whether the CMJ20cm predicts V1load and 1RM in the full-squat exercise

In a study where they analyzed effects of velocity-based resistance training on young soccer players of different ages, the load that elicited V1load in the under-21 team was 53.1 ± 4.9 kg (González-Badillo et al., 2015), in comparison to the 61.5 ± 13.7 kg reported in this study. Our sprinters showed 15% higher V1load compared to the soccer players. Nevertheless, the reported 1RM squat values in this study (102.8 ± 21.2 kg) are significantly lower in comparison to the data collected in the South Dakota State University, where they compared the relationship between relative strength levels to sprinting performance in collegiate 100-400m sprinters in the squat exercise (149.85 ± 32.75 kg), (Reuer, 2017). However, an experiment involving eight world-class elite and sub-elite male sprinters (100m) compared the CMJ between elite and sub-elite athletes, and found a statistical significant difference of 13 cm, 57 ± 3 cm in the elite sprinters and 44 ± 1 cm in the sub-elite sprinters (Beattie, Tawiah-Dodoo, & Graham-Smith, 2020). The mean CMJ of the participants in this study was 44.4 ± 3.5 cm, very similar to those sub-elite sprinters of the abovementioned study. Although it is difficult to compare our results with the ones of other studies due to methodological differences, these comparisons suggest that the participants who took part in our study are a representative sample of national-level 200m runners. Reported data might be of interest to create solid normative data for elite runners and serve as reference for potential young promises.

Concerning relationships between unloaded and loaded vertical jump, CMJ correlated *largely* ($r = 0.66$; $P = 0.01$; SEE = 2.69; 95% CI = 0.109 to 3.360) with CMJ20cm, with SEE being 5.9% of the mean (Figure 7). This relationship indicates that those sprinters with higher CMJ habitually jump higher in the CMJload test. Jiménez-Reyes et al. (2001) analyzed the relationship between jumping and acceleration capacity in sprinters and obtained significant relationships between the CMJ ($r=-0.65$, $p<0.01$) and the loaded CMJ in the CMJLoad test ($r=-0.56$, $p<0.0$) with progressive sprints. These results strongly support the election of CMJ and CMJloaded for the assessment of strength in sprinters, due to the relationships between the CMJ and CMJ20cm and sprint performance demonstrated by others (Jimenez-Reyes et al., 2001). CMJ20cm could be predicted with the unloaded CMJ, although with low accuracy, with the following equation:

CMJ (cm) = 1.8473(CMJ20cm (kg)) - 36.264

There are several studies that establish the relationship between CMJ and the full squat exercise with different loads (Carlock et al., 2004; Griggs, 2016; Nuzzo, McBride, Cormie, & McCaulley, 2008; Young., Wilson, & Byrne, 1999). A study conducted with a sample of powerlifters found a significant ($r = 0.62$) relationship between relative 1RM back squat and CMJ height (Griggs, 2016). Similar results were found in other articles (Carlock et al., 2004; Young et al., 1999). In contrast, when compared to absolute squat 1RM, one study (Nuzzo et al., 2008) did not find a significant correlation with CMJ height ($r = 0.219$). Similar findings were reported by Young and Bilby (1993). However, the estimation 1RM or V1load performance from a CMJ was not very accurate in the present study. CMJ *moderately* correlated with V1load and 1RM ($r = 0.47$ and 0.485, respectively), (Figure 8, A & B). Despite significant relationships, the estimation error for V1load and 1RM (SEE >12%) indicates that it may not be of practical use due to low estimation precision.

To the best of our knowledge, this is the first study analyzing the relationships between the CMJ20cm with the V1load and 1RM obtained in the full squat exercise. The load associated with 20cm in the loaded CMJ exercise was closely related to the V1load and 1RM variables in the full squat exercise ($r = 0.806$ and 0.81, respectively), with relatively low estimation error (SEE <12%), (Figure 8, C & D). Given the strength of the relationships and relatively low SEE, the equations reported in this study (Figure 8, C & D) might be of clinical on field value. Equations for coaches to be use are the following:

1RM (kg) = 1.7526(CMJ20cm (kg)) + 22.492

V1load (kg) = 1.1226(CMJ20cm (kg)) + 10.077

The results of this study strongly support the use of CMJ20cm to precisely estimate the V1load and 1RM in the full-squat exercise in 200m and 400m runners. The on-field use of these equations might alleviate the burden associated with V1load and 1RM testing and facilitate the on-going monitoring of training-induced strength adaptations. These equations might also serve to re-adjust the strength training loads in a more frequent manner.

Limitations

It is important to point out some limitations. It is hard to compare these results with other studies given the methodological differences. Most studies use peak power as a reference, however, mean propulsive velocity was used in this study. Mean propulsive velocity, apart from reflecting neuromuscular potential in ballistic exercises like the ones used for this study, it also reflects performance in non-ballistic exercises, so it might be a more suitable measure to predict functional performance (Loturco et al., 2017).

It is essential to underline that the relationships have been found in a specific sample of runners and therefore we do not know whether they will be repeated in another sample. Therefore, results cannot be generalized. On the other hand, it is a cross-sectional study. For this reason, relationships will have to be confirmed in cross-validation studies (to validate the equations) and in longitudinal studies (to see if we can establish a solid cause-and-effect relationship between the predictor variable and the predicted variables). The suggested formulas are not perfect and if used properly, real values can be underestimated or overestimated. It is recommended to use our same methodological procedures if our reported equations are going to be utilized.

With regard to the procedure, a couple of things should also be pointed out. Unlike the study conducted by Jimenez-Reyes et al. (2016) where they employed 2 linear transducers and a force platform, this study only used an infrared timing system for measuring height in the unloaded and loaded exercises. Kinematic data without a force platform is less accurate and ground reaction forces (GRF) are often underestimated resulting in less power production (Ancillao, Tedesco, Barton, & O'Flynn, 2018). For coaches without means to purchase an accurate device to measure jump height, the smartphone app “My Jump 2” could be employed as an alternative. It is the first app scientifically developed to measure jump height and validated by sport scientists (Gallardo-Fuentes et al., 2016). Apart from that, for proper performance, a correct technique is required to reduce the chances of injury to a minimum, and also a Smith Machine is recommended, which is usually available at any local gym.

Conclusions and Practical Applications

CMJ20cm has been proven to be a more accurate tool than the standard CMJ to predict 1RM and V1load in the full squat exercise. Additionally, in order to manage a big team of athletes from different backgrounds, the present study encourages coaches to use these equations to estimate the current performance of an athlete in the 1RM and V1load in the full squat from another more functional strength exercise to facilitate resistance training guidance. This is of great importance for several reasons. For one thing, there is no need for a linear transducer, as only the height reached is needed, nor is there any need for such a large effort involved in the 1RM. Therefore, being able to execute one exercise (CMJloaded) instead of three (CMJ, 1RM and V1load) is more time efficient and thus allows coaches to invest their time in other tasks. Due to the estimation errors using these equations, it is recommended to, at least once every season (e.g. commencing of the running season), measure all the strength performance markers in all the strength exercises in this kind of sprinting athletes, and use the equations to monitor the strength training-induce adaptations more frequently along the season, or in periods when a testing-window is no plausible.

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