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Movement velocity as a measure of exercise intensity in three lower limb exercises

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ABSTRACT

The purpose of this study was to investigate the relationship between movement velocity and relative load in three lower limbs exercises commonly used to develop strength: leg press, full squat and half squat. The percentage of one repetition maximum (%1RM) has typically been used as the main parameter to control resistance training; however, more recent research has proposed movement velocity as an alternative. Fifteen participants performed a load progression with a range of loads until they reached their 1RM. Maximum instantaneous velocity (V_{max}) and mean propulsive velocity (MPV) of the knee extension phase of each exercise were assessed. For all exercises, a strong relationship between V_{max} and the %1RM was found: leg press (r^2_{adj} = 0.96; 95% CI for slope is [−0.0244, −0.0258], $P < 0.0001$), full squat (r^2_{adj} = 0.94; 95% CI for slope is [−0.0144, −0.0139], $P < 0.0001$) and half squat (r^2_{adj} = 0.97; 95% CI for slope is [−0.0135, −0.00143], $P < 0.0001$); for MPV, leg press (r^2_{adj} = 0.96; 95% CI for slope is [−0.0169, −0.0175], $P < 0.0001$, full squat (r^2_{adj} = 0.95; 95% CI for slope is [−0.0136, −0.0128], $P < 0.0001$) and half squat (r^2_{adj} = 0.96; 95% CI for slope is [−0.0116, 0.0124], $P < 0.0001$). The 1RM was attained with a MPV and V_{max} of 0.21 ± 0.06 m s^{-1} and 0.63 ± 0.15 m s^{-1}, 0.29 ± 0.05 m s^{-1} and 0.89 ± 0.17 m s^{-1}, 0.33 ± 0.05 m s^{-1} and 0.95 ± 0.13 m s^{-1} for leg press, full squat and half squat, respectively. Results indicate that it is possible to determine an exercise-specific %1RM by measuring movement velocity for that exercise.

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KEYWORDS
Resistance training; movement velocity; intensity; strength

Introduction

The training variables traditionally manipulated to prescribe and control resistance training programs are typically repetitions, sets, interval time and intensity (Bird, Tarpenning, & Marino, 2005; Kraemer & Ratamess, 2004; Pereira & Gomes, 2003). Of these, exercise intensity is widely recognised as the most important variable in resistance training and is normally reported as a percentage of the individuals one repetition maximum, %1RM, the maximum load that can be lifted in a single lift (Fry, 2004; Kraemer & Ratamess, 2004; Pereira & Gomes, 2003). In order to report this value, it is therefore necessary to first establish the 1RM for each participant and exercise.

There are three methods normally used to determine the 1RM: (i) the direct method, which consists of measuring the maximum weight that can be lifted in a single lift; this method is generally applied to athletes and trained individuals, (ii) the prediction method, which estimates the 1RM from the execution of several submaximal repetitions and uses conversion factors or regression equations and (iii) methods based on movement velocity.

Maximal tests to measure force are commonly used to test an athlete's muscular strength. Although the measurement of a single maximal lift is the gold standard method for force evaluation (Franklin, Whaley, Howley, & Balady, 2000), it may not represent the true maximum of the participant when the exercise is performed incorrectly or by inexperienced participants (González-Badillo & Sánchez-Medina, 2010). This method can be dangerous for young athletes or individuals not accustomed to weight training since it may induce muscle soreness or risk of muscular injury (Braith, Graves, Leggett, & Pollock, 1993). Others claim that this method is time consuming and difficult for elderly and physically inactive participants (Rontu, Hannula, Leskinen, Linnamo, & Salmi, 2010).

Prediction methods are the most commonly used in health and fitness training, when a single maximum lift might pose a health or injury risk (Brzycki, 1993; Mayhew et al., 1995, 2002; Reynolds, Gordon, & Robergs, 2006). These equations are derived from the heaviest possible load the participant is able to lift for a predetermined number of repetitions, a given load for as many repetitions as it is possible in a predetermined time or inducing fatigue within a specific range of repetitions (Chapman, Whitehead, & Binkert, 1998). Therefore, many prediction methods common in strength training practice employ exhaustive efforts. Increasing evidence shows that training to failure does not necessarily improve muscular strength gains and may even be counterproductive since it can induce excessive fatigue, mechanical and metabolic strain and possibly undesirable transition to slower fibres (Fry, 2004).

Another way to monitoring strength training is based on movement velocity. Although the relationship between velocity and force was established nearly a century ago (Hill, 1938), it has not been used as a method to control load intensity in resisted training. Several authors have stressed the importance

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of velocity in the prescription and control of resistance training, although until recently it was not possible accurately to measure velocity in typical strength training exercises. The vast majority of research linking velocity and strength training were conducted using isokinetic devices which enable only non-natural movements and are not a common form of training. However, recent studies have established a relationship between movement velocity and %1RM for a variety of exercises such as the bench press (González-Badillo & Sánchez-Medina, 2010; Jidovtseff, Harris, Crielaard, & Cronin, 2011; Rontu et al., 2010) and squat jump (Randell, Cronin, Keogh, Gill, & Pedersen, 2011). These authors demonstrated that it was possible to estimate %1RM from a measurement of movement velocity using a linear regression equation.

It was found for the studies incorporating the bench press that: (i) accurate predictive equations can be established using submaximal loads with small differences between estimated and measured strength (Rontu et al., 2010); (ii) there is no need to perform a 1RM or test the maximum number of repetitions to failure; (iii) the %1RM being used could be determined as soon as the first repetition for any given submaximal load and (iv) training load can be prescribed and monitored according to movement velocity.

Therefore, there may be a number of advantages to the resistance training coach and athlete: (i) greater accuracy in prescription and adaptation of resistance exercises, (ii) the possibility to accurately determine a %1RM value, (iii) real-time feedback of the %1RM and movement velocity in each repetition during the training session, (iv) the ability to safely evaluate participants with little training experience and (v) the possibility of estimating neuromuscular fatigue during a set (González-Badillo & Sánchez-Medina, 2010, 2010; Jidovtseff et al., 2011; Rontu et al., 2010).

At present, these applications are limited to the bench press on which the research was carried out (Argus, Gill, Keogh, & Hopkins, 2011; González-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011; Rontu et al., 2010) and squat jump (Randell et al., 2011). Therefore, the purpose of this study was to investigate the relationship between movement velocity and the %1RM for the lower body resistance exercises of leg press, full squat and half squat.

Methods

Participants

A total of 15 male athletes, jumpers and sprinters from track and field athletics, took part in this study. All track and field athletes competed at national and/or international level. The mean age, body mass and stature of the participants were 21 ± 3.61 years old, 70.1 ± 14.5 kg and 1.78 ± 0.07 m, respectively. The inclusion criteria for this study were defined as: (a) at least 2 years of experience in resistance training; (b) to be engaged with resistance exercise on at least two occasions during the week; (c) familiarity with performing the exercises used in the experiment and (d) between 18 and 30 years of age. Exclusion criteria were: (a) previous injuries that might interfere with the study and (b) taking medications or anabolic steroids.

All participants freely provided written informed consent to participate in the study in line with the process approved by the local ethics committee of the University of Porto (Porto, Portugal) and in agreement with the Declaration of Helsinki.

Experimental procedures

To analyse the relationship between movement velocity and the %1RM of the exercises, a cross-sectional study design was used.

Three exercises were studied: the leg press, full squat and the half squat, since they are considered fundamental resistance exercises for the lower limbs (Bird et al., 2005; Kraemer & Ratamess, 2004; Pereira & Gomes, 2003). In the first session, participants went to the laboratory and the researcher provided an explanation of the protocol in addition to familiarising them with the instruments. Participants were instructed on how to perform the exercises for the purposes of this study, using medium loads. At least 48 h was provided between familiarisation and the start of the data collection sessions.

Prior to data collection, the participants were informed of the procedures. All participants were provided 10 min to complete a self-designed warm-up consistent with their normal training routine. Initially, a heart rate monitor was placed on the participant to control the running warm-up intensity. Each participant performed a slow 5-min treadmill run, at 60% of their maximum heart rate, followed by stretching and joint mobilisation exercises of the lower body. Finally, they performed five repetitions of the exercise to be assessed, with light loads – 20 kg for the half and full squat and 60 kg for the leg press. Participants were instructed to perform the lower limb knee flexion in a controlled manner until they attained full knee flexion for the full squat and leg press or 90° for the half squat. They were then asked to hold this position for approximately 3–4 s and then extend the knee explosively as fast as possible following a command provided by the investigator. This was to eliminate the contribution of elastic energy that could come for muscle tendon unit stretching since the interest is in the concentric action performed during knee extension and not the effect of the stretch shortening cycle. A modified Smith machine and inclined leg press machine were used to ensure linear movements, a requirement of the velocity measuring device. During each trial, participants were encouraged to perform knee extension with maximum voluntary velocity.

Instrumentation

To perform the warm-up and control intensity a treadmill AMTI Force sensing tandem treadmill (AMTI, Watertown, MA, USA) and RS polar RS 100 (Polar Electro, Kempele, Finland) were used.

Bar velocity was measured using a linear transducer sampling at 1000 Hz (T-Force System, Ergotech, Murcia, Spain) connected to a 16-bit analogue to digital converter (Biopac MP100 Systems, Santa Barbara, CA, USA) (Figure 1a,b).

The T-force System was interfaced with a personal computer to automatically calculate the relevant kinematic and kinetic parameters for every repetition, providing real-time feedback and data storage. To standardise the starting joint configurations in each repetition, the knee joint angle was measured using an electrogoniometer (Penny & Gilles, Biometrics Ltd.,

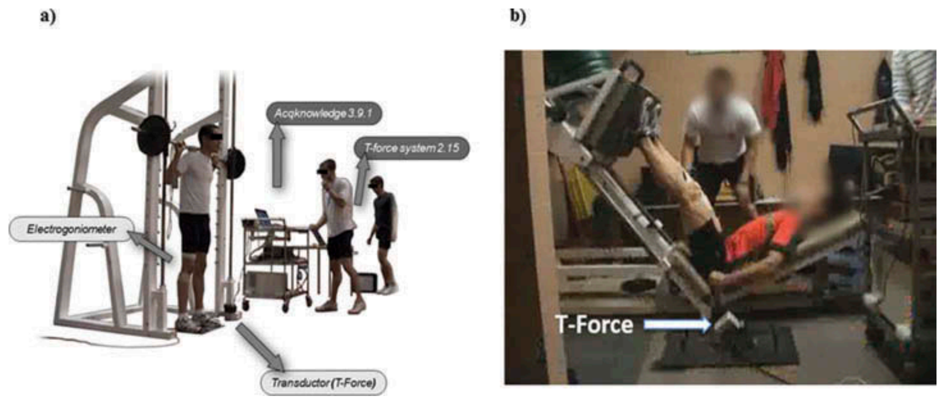

Figure 1. General set-up protocol for (a) the squat and (b) leg press.

Blackwood Ltd., London UK). The full squat and half squat exercises were conducted using a Smith machine (Multipower Fitness Line, Peroga, Spain), while for the leg press a custom-built 45º leg press machine was used (Figure 1a,b).

Data collection

All participants had at least 48 h of rest from their training routines prior to the test sessions and reported no fatigue at the start of each test session. The protocol consisted of three sessions selected in random order with a minimum interval of 5 days between each session. One session was dedicated to the leg press and the other session was dedicated to the full squat or the half squat.

A load progression was conducted for each exercise with six to eight load increments, starting from 20 kg in the half squat and full squat exercises (≈20% 1RM) and 60 kg in the leg press (≈30% 1RM). Similar to bench press studies, increments in each load were approximately 10% 1RM until reaching a mean propulsive velocity (MPV) of 0.5 $m{\cdot}s^{-1}$ (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010), followed by increments of 5 to 1 kg until 1RM was achieved. For those loads moved at a MPV up to 1.15 $m{\cdot}s^{-1}$, four repetitions were performed with a 3- to 4-min rest interval; two repetitions for medium loads (0.5 $m{\cdot}s^{-1}$ ≤ MPV ≤ 1.15 $m{\cdot}s^{-1}$), with 5-min rest and one repetition (MPV < 0.5 $m{\cdot}s^{-1}$) for maximum loads and 6-min recovery. The right knee angle was measured to ensure consistent knee joint angles for each repetition in the load progression. Knee joint angle was defined as zero degrees when the leg was extended. The command provided by the researcher to the participant to initiate the knee extension for the half squat was given when knee flexion had reached 90º or for the full squat and leg press knee flexion was fixed at 115°, a requirement for the repetition to be accepted for further analysis.

Participants received real-time velocity feedback and were provided with verbal encouragement to exert their maximum effort.

Data analysis

Instantaneous velocity was sampled at 1000 Hz. The velocity data were calibrated and filtered according to the T-force software specifications (Sánchez-Medina & González-Badillo, 2011). The propulsive phase was defined as the portion of the knee extension during which the measured acceleration was greater than the acceleration due to gravity, the positive net acceleration (Figure 2) (Sanchez-Medina et al., 2010). This parameter refers to the portion of the knee extension when the applied force is positive in the direction of the movement and thus does not consider the braking phase where the acceleration is smaller than that of the gravity. The relative contributions of the propulsive and braking phases during knee extension for the half squat are shown in Figure 2.

Displacement was obtained by the integration of the velocity with respect to time, the acceleration by differentiation of the velocity with respect to time and instantaneous force calculated as $F = m{\cdot}(a + g)$ where m is the moving load (kg) and g is the gravitational acceleration.

Two main parameters were analysed: the MPV and the maximum velocity (V_{max}). A full squat, leg press and half squat repetition was only selected for further analysis when the knee joint angle at the start of the limb extension met the joint angle criteria. To establish the relationship between force and movement velocity as a measure of intensity, the two best repetitions were selected at light and medium loads and only one for maximum load was considered for analysis. The criterion was those repetitions with the fastest MPV (González-Badillo & Sánchez-Medina, 2010).

Statistical procedures

Initially, all the data were entered into a spreadsheet (Excel Microsoft software Corporation, Seattle, WA, USA). To examine any difference in the form of the relationship between MPV and %1RM and V_{max} and %1RM data were plotted and fitted by first-order linear polynomials. The degree of linear correlation between movement velocity and the %1RM was examined using Pearson's product moment correlation (r), R square (r^2) and R^2 adjusted (r^2_{adj}). The confidence interval (CI) was set at 95%. To test the gradients and intercepts of the regression equations, they were compared with Z-tests using Graphpad Prism 5.0.1 for Windows (GraphPad Software, San Diego, CA, USA). When interactions were not significant, analyses were completed by testing the intercepts. To avoid performing a multifactorial Z-test, we used the simple Bonferroni correction. An alpha level of 0.05 was established for statistical significance level.

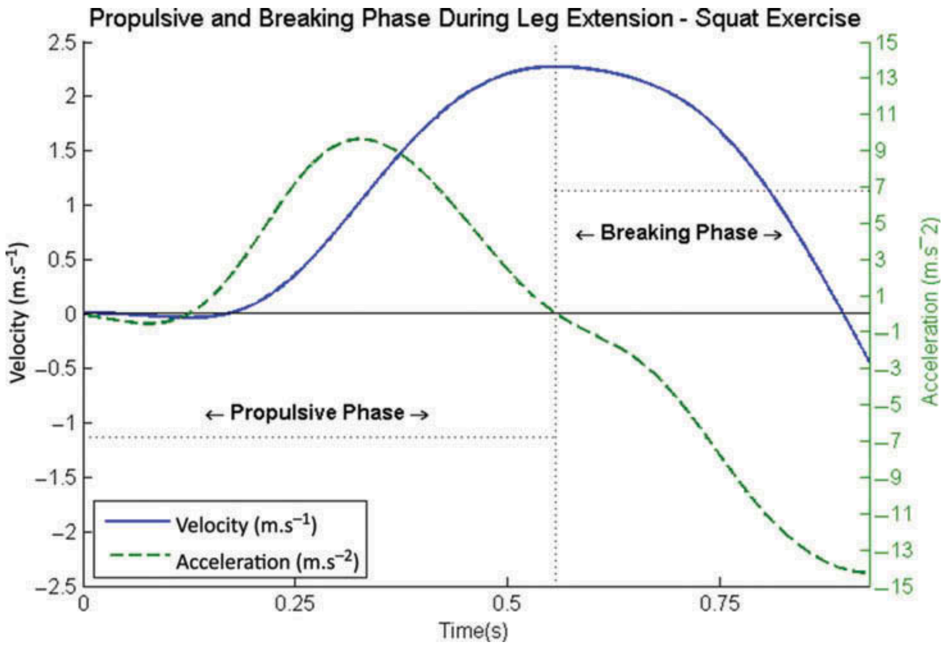

Figure 2. Curve velocity, acceleration time obtained during half squat with 30% load of 1RM by one of the participants of the sample. Propulsive and breaking phase are delimited by the point where acceleration intersects the *x*-axis.

Results

The mean and SD of the best performances obtained were: leg press, 1RM = 235.2 ± 40.7 kg; full squat, 1RM = 124.2 ± 26.6 kg and half squat, 1RM = 145.0 ± 46.5 kg. For all exercises, a strong relationship between V_{max} and the %1RM was found: leg press (r^2_{adj} = 0.96; 95% CI for slope is [−0.0244, −0.0258], P < 0.0001), full squat (r^2_{adj} = 0.94; 95% CI for slope is [−0.0144, −0.0139], P < 0.0001) and half squat (r^2_{adj} = 0.97; 95% CI for slope is [−0.0135, −0.00143], P< 0.0001), as shown in Figure 3. Similar results were observed in the MPV and the %1RM relationship: leg press (r^2_{adj} = 0.96; 95% CI for slope is [−0.0169, −0.0175], P < 0.0001), full squat (r^2_{adj} = 0.95; 95% CI for slope is [−0.0136, −0.0128], P < 0.0001) and half squat (r^2_{adj} = 0.96; 95% CI for slope is [−0.0116, −0.0124], P < 0.0001), as also shown in Figure 3.

The 1RM was attained with an MPV of 0.21 ± 0.03 m·s^{-1} for the leg press, 0.30 ± 0.04 m·s^{-1} for the full squat and 0.33 ± 0.03 m·s^{-1} for the half squat. Concerning V_{max}, the 1RM was achieved with a propulsive velocity of 0.62 ± 0.13 m·s^{-1} for the leg press, 0.91 ± 0.14 m·s^{-1} for the full squat and 1.01 ± 0.07 m·s^{-1} for the half squat (Table 1). The changes in the MPV at each 5% load increment in the leg press, full squat and half squat are shown in Table 2. Increments are fairly stable throughout the entire range of relative percentages which allowed a linear relationship to be defined between load intensity and movement velocity.

For all the exercises, the differences between the V_{max} and %1RM gradients and the MPV and %1RM gradients were statistically significant as presented in Table 3 (leg press: P < 0.0001, full squat: P = 0.006, half squat: P < 0.0001).

After testing the slopes for the same exercise in pairs, we move on to test all the slopes of all the exercises. We found that the slopes were statistical different with P < 0.001 except between V_{max} half squat and V_{max} full squat where P = 0.055 (Table 4).

Regression equations can be derived to enable the calculation of the percentage 1RM being lifted based on the MPV of the movement. These equations are as follows:

(a) Full squat, load = −71.684 × (MPV) + 121.03; r^2_{adj} = 0.95; 95% CI for slope is [−69.41, −74,137], P < 0.001

(b) Half squat, load = −80.372 × (MPV) + 125.19; r^2_{adj} = 0.96; 95% CI for slope is [−77.95, −82,289], P < 0.001

(c) Leg press, load = −55.509 × (MPV) + 109.29; r^2_{adj} = 0.96; 95% CI for slope is [−53.883, −57.134], P < 0.001

Following a comparison of V_{max} slopes for full squat and half squat, we investigated their intercepts, which revealed they were significantly different (P < 0.0001). Differences between the maximum velocity–load relationship (gradient) for the full squat and half squat were small. For this reason, a common equation could be defined for both exercises by assuming their gradients to have equal magnitude. Therefore doing so a new common equation for both these exercises has been established (Figure 4).

Full squat and half squat, load = −68.581 × (V_{max}) + 2.512; r^2_{adj} = 0.96; 95% CI for slope is [−67.156, −70.005], P < 0.001.

Discussion

The results obtained here indicate a strong relationship between the maximum instantaneous velocity and the % 1RM for three lower body resistance exercises – full squat, half squat and leg press. These results are in agreement with previous studies that identified a relationship between the movement velocity and %1RM for the bench press (González-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011; Rontu et al., 2010).

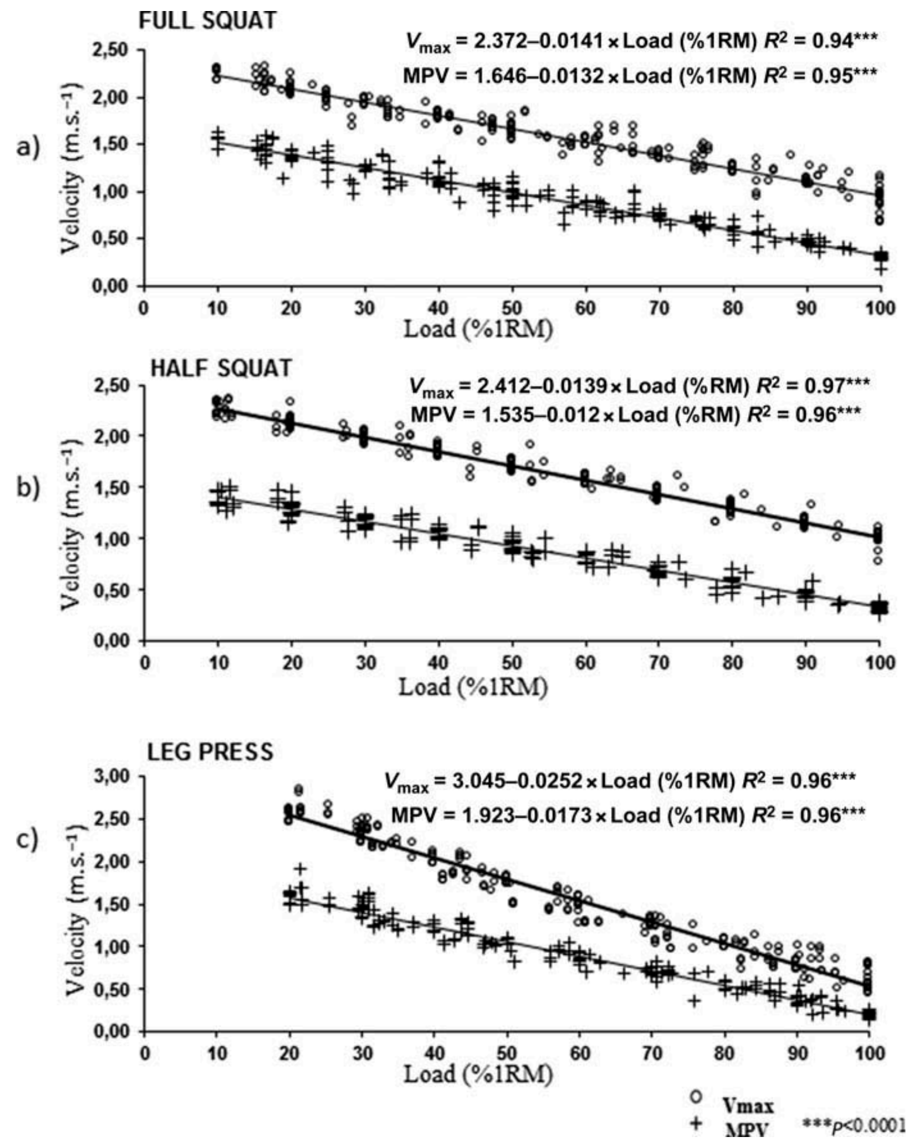

Figure 3. Measurement of relative load and V_{max} (round dots), relative load and MPV (crosses) for the (a) full squat, (b) half squat and (c) leg press.

Table 1. Maximum instantaneous velocity and mean propulsive velocity when the 1RM is attained during each of the exercises (mean ±SD).

Exercise	Maximum velocity ($m{\cdot}s^{-1}$)	Mean propulsive velocity ($m{\cdot}s^{-1}$)
Full squat	0.91 ± 0.14	0.30 ± 0.04
Half squat	1.01 ± 0.07	0.33 ± 0.04
Leg press	0.62 ± 0.13	0.21 ± 0.04

Table 2. Predicted mean propulsive velocity ($m{\cdot}s^{-1}$) for the leg press, squat and half squat at each intensity (%1RM).

Load (% 1 RM)	Leg press	Squat	Half squat
15	1.66	1.45	1.35
20	1.58	1.38	1.29
25	1.49	1.32	1.23
30	1.4	1.25	1.17
35	1.32	1.18	1.11
40	1.23	1.12	1.05
45	1.15	1.05	0.99
50	1.06	0.99	0.93
55	0.97	0.92	0.87
60	0.89	0.85	0.81
65	0.79	0.79	0.75
70	0.71	0.72	0.69
75	0.63	0.66	0.63
80	0.54	0.59	0.57
85	0.45	0.52	0.51
90	0.37	0.46	0.45
95	0.28	0.39	0.39
100	0.19	0.33	0.33

Our results reveal that when knee extension for these exercises is performed at maximal velocity, the %1RM can be estimated for each repetition with real-time feedback. To measure the %1RM of repetitions exclusively using maximal knee extension velocity may complement the training process as a form of athlete monitoring, since maximal velocity lifts have been proposed as an effective resistance training method (Bell, Petersen, MacLean, Reid, & Quinney, 1992; Bell & Wenger, 1992; Cronin, McNair, & Marshall, 2002; Garcia-Pallares, Sanchez-Medina, Perez, Izquierdo-Gabarren, & Izquierdo, 2010; Hasegawa, 2010; Sánchez-Medina & González-Badillo, 2011). Maximum velocity lifts have been proposed to: (i) increase motivation (Hasegawa, 2010), (ii) maintain the intended movement velocity to maximise the intra- and inter-coordination of neuromuscular units (Garcia-Pallares et al. (2010); Hasegawa, 2010), (iii) be

Table 3. Comparison between the slopes of V_{max}, to %1RM versus MPV, to %1RM for full squat, half squat and leg press.

Variable 1	Variable 2	Slope comparison
V_{max} – % 1RM of full squat	MPV – % 1RM of full squat	$P = 0.0067$
V_{max} – % 1RM of half squat	MPV – % 1RM of half squat	$P < 0.0001$
V_{max} – % 1RM of leg press	MPV – % 1RM of leg press	$P < 0.0001$

Table 4. Comparison between the slopes of the relationship movement velocity versus relative load, for the V_{max} in the full squat, half squat and leg press for the MPV in the full squat, half squat and leg press.

Relationship slope	Relationship slope	Slope comparison
a. V_{max} full squat	V_{max} half squat	$P = 0.0552$
V_{max} full squat	V_{max} leg press	$P < 0.0001$
V_{max} half squat	V_{max} leg press	$P < 0.0001$
b. MPV full squat	MPV half squat	$P < 0.0001$
MPV full squat	MPV leg press	$P < 0.0001$
MPV half squat	MPV leg press	$P < 0.0001$

more effective for advanced training than traditional slow velocities performed with moderately high loads (Jones, Hunter, Fleisig, Escamilla, & Lemak, 1999; Kraemer & Ratamess, 2004), (iv) increase anaerobic power output (Bell et al., 1992), (v) promote a change in skeletal muscle size and change in myofibrillar ATPase activity (Bell et al., 1992; Bell & Wenger, 1992) and (vi) monitor the degree of incurred fatigue (González-Badillo, Marques, & Sánchez-Medina, 2011; Sánchez-Medina & González-Badillo, 2011).

The relationship between %1RM and movement velocity was found to be specific to the resistance exercise. Small standard deviations (Table 1) were found for the mean propulsive velocities attained at the 1RM, especially when the MPV is used. These results suggest that MPV may be a more precise method for predicting the 1RM. When using the full range of loads, both the MPV and V_{max} can be used with confidence to determine the %1RM for that exercise (Table 2).

A strong movement velocity to %1RM relationship was found elsewhere for the bench press (González-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011; Rontu et al., 2010), and the current research has extended that understanding to the exercises of full squat, half squat and leg press. A common equation can describe the relationship between V_{max} and the %1RM for the full squat and half squat, and this is most likely to result from a half squat being a sub-unit of the full squat exercise (Figure 4). Since the results demonstrated a similar gradient for half squat and full squat versus %1RM with differences predominantly in the intercepts, a general equation can be used for both. Both exercises behave similarly (Figure 4) and their main differences are in absolute values, i.e. the magnitude of the load. Another interesting fact is that the leg press presents significant difference with the gradients and intercepts of the full squat and half squat, despite recruiting similar muscle groups. Potentially, these differences lie with the hip position which relates to some muscles operating on different parts of their force length relationship. Without multi-joint kinematic data, it is only possible to speculate.

The route mean square difference between measured and calculated %1RM from MPV using regression equations was 5.8%, 7.3% and 7.7% for the leg press, full squat and half squat, respectively. Since the equations for defining full and half squats were so similar, it was of interest to investigate how their respective equations might affect calculated %1RM when using the other movement's equation. When the equation for calculating the percentage of 1RM from MPV of the full squat was employed to calculate the percentage of 1RM for the half squat, there was a route mean square difference of 8.5% as compared to a route mean square difference of 7.7% obtained using its own equation. When employing the equation for calculating the percentage of 1RM from MPV of the half squat to calculate the percentage of 1RM for the full squat, there was a route mean square difference of 8.4% as compared to the rout mean square difference 7.3% when using its own equation.

A strong relationship was found between MPV and load for the leg press, full squat and half squat which can be seen in Figure 3, with r^2_{adj} values of 0.96, 0.95 and 0.96, respectively. Previous investigations conducted for the bench press exercise also revealed a close relationship ($r^2 = 0.98$) between relative load (%1RM) and movement velocity (González-Badillo & Sánchez-Medina, 2010). This strong relationship can be used to predict or adjust the 1RM value during a training session simply by measuring the execution velocity. Note that due to fatigue and other conditions, the 1RM values fluctuate between training sessions. It was interesting to verify that the

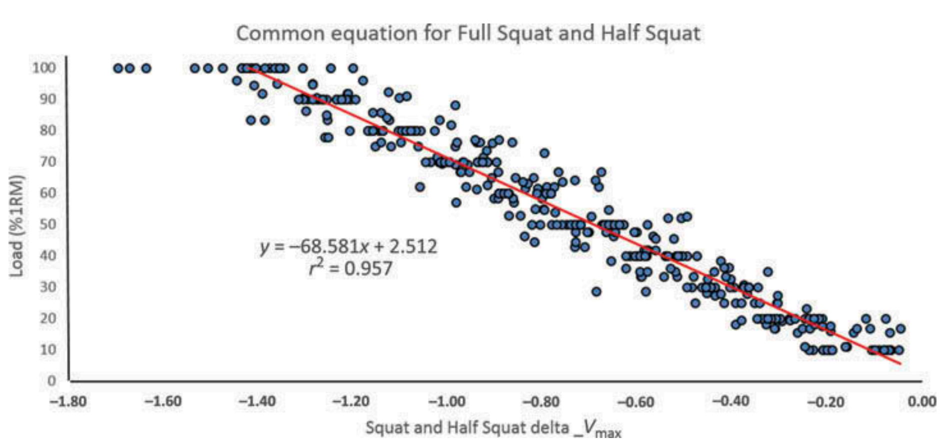

Figure 4. Common predictive equation for relative load and V_{max} for combined squat and half squat data.

propulsive velocity difference between 5% load increments from 30% to 100% of 1RM for leg press, squat and half squat were 0.087, 0.066 and 0.06 m·s^{-1}, respectively (Table 2). As noted by González-Badillo and Sánchez-Medina (2010), when a participant increases their MPV by an increment as shown above, then this might be used to establish a 5% increase in strength. These are multi-joint exercises and involve some of the largest and most powerful muscles of the body, which may explain why the velocities measured in this study were larger than those found in the literature for the bench press.

Some questions might be raised regarding the value in being able to approximate load from movement velocity as a tool to develop strength: Which is best – fast or slow lifts? Is it appropriate to adopt fast lifts over slow lifts to enhance strength gains?

Most research conducted in the past that attempted to answer these questions was inconclusive, and this was most likely the result of methodological inconsistences such as: (i) not equating volume and loading magnitude between different training interventions (Fielding et al., 2002; Pereira & Gomes, 2003); (ii) the use of exercise sets performed up to or close to muscle failure, which tends to equalise the overall training velocities between fast and slow velocities such that they are very similar (Cronin, McNair, & Marshall, 2001) and (iii) the velocities were not rigorously controlled (Ingebrigtsen, Holtermann, & Roeleveld, 2009).

More recent research by González-Badillo, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, and Pareja-Blanco (2014) has suggested that movement velocity may be considered the most important factor in resistance training since at a given magnitude (%1RM), the velocity at which the load is moved determines the resulting training effect. By comparing 6 weeks of strength training with loads moved at maximum velocity or at half of maximum velocity, the strength gains were larger in the fast group relative to the slower one. Moreover, these results were obtained without participants exceeding half of the maximum possible number of repetitions possible per set. The explanation for the superior strength gain from the faster lifting techniques has been proposed to be the increased activation of agonist muscles required to overcome the load with fast concentric muscle actions (Sakamoto & Sinclair, 2012) where larger peak forces are attained for each repetition (Hatfield et al., 2006).

Our results show similar correlations between movement velocity and %1RM to those found in the literature (González-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011; Rontu et al., 2010), and therefore the full squat, half squat and leg press exercises may benefit from the same advantages: (i) prediction of 1RM with submaximal loads available from the first repetition of each training session (Jidovtseff et al., 2011; Rontu et al., 2010), (ii) calibration of training load from daily athlete performance level and (iii) continuous evaluation of resistance training progress (Jidovtseff et al., 2008).

The present method imposed pauses of 3–4 s between the eccentric and concentric phases. The purpose of this design was the elimination of the stretch shorten cycle effects in the force developed. A pause between the eccentric and concentric contraction appears to be good practice since it leads to the minimisation of the measured error by reducing the variability in the measurements and producing more reliable isoinertial assessment. Although it is not common in training practice and may affect the ecological validity, some compromise is required in order to employ a method of field-based assessment with high reliability (Reilly, Morris, & Whyte, 2009).

Last, although movement velocity has a very close relationship to %1RM (Sanchez-Medina et al., 2010) and could be used as a more valuable parameter in the training control process than the 1RM, this procedure could present some potential limitations because it requires adequate experience from the athlete to avoid underestimating the intensity. Whilst expensive equipment has been used to acquire the data for this study, a range of inexpensive video-based analysis systems might be used to recreate a similar method of calculation in an applied setting with only a limited effect on measurement error.

Conclusions

Based on the results obtained in this study, it is proposed that for athletes with competent and consistent lifting techniques, the MPV should be used to estimate the %1RM in the full squat, half squat and leg press exercises, using the equations presented in the results section.

Strength and conditioning practitioners may choose MPV or V_{max} to predict and/or monitor the %1RM without the need to perform a 1RM test. A range of inexpensive video analysis software could be used to achieve this.

In conclusion, the results obtained in this study indicate that the %1RM can be estimated for each repetition during strength training sessions using real-time feedback. Strength can be estimated from movement velocity and submaximal loads and hence avoid the potential increased injury risk from the standard 1RM protocol.

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References

Argus C. K., Gill N. D., Keogh J. W. L., & Hopkins W. G. (2011). Acute effects of verbal feedback on upper-body performance in elite athletes. *Journal of Strength and Conditioning Research*, *25*(12), 3282–3287.

Bell G. J., Petersen S. R., MacLean I., Reid D. C., & Quinney H. A. (1992). Effect of high velocity resistance training on peak torque, cross sectional area and myofibrillar ATPase activity. *The Journal of Sports Medicine and Physical Fitness*, *32*, 10–18.

Bell G. J., & Wenger H. A. (1992). Physiological adaptations to velocity-controlled resistance training. *Sports Medicine*, *13*, 234–244.

Bird S. P., Tarpenning K. M., & Marino F. E. (2005). Designing resistance training programmes to enhance muscular fitness: A review of the acute programme variables. *Sports Medicine*, *35*, 841–851.

Braith R., Graves J., Leggett S., & Pollock M. (1993). Effect of training on the relationship between maximal and submaximal strength. *Medicine & Science in Sports & Exercise*, *25*, 132–138.

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

Chapman P. P., Whitehead J., & Binkert R. (1998). The 225-lb reps-to-fatigue test as a submaximal estimate of 1-RM bench press performance in college football players. *Journal of Strength Conditioning Research*, *12*, 258–261.

Cronin J., McNair P. J., & Marshall R. N. (2001). Velocity specificity, combination training and sport specific tasks. *Journal of Science and Medicine in Sport*, *4*, 168–178.

Cronin J. B., McNair P. J., & Marshall R. N. (2002). Is velocity-specific strength training important in improving functional performance? *Journal of Sports Medicine and Physical Fitness*, *42*, 267–273.

Fielding R. A., LeBrasseur N. K., Cuoco A., Bean J., Mizer K., & Fiatarone Singh M. A. (2002). High-velocity resistance training increases skeletal muscle peak power in older women. *Journal of the American Geriatrics Society*, *50*, 655–662.

Franklin B. A., Whaley M. H., Howley E. T., & Balady G. J. (2000). *American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription* (6th ed.). Philadelphia: Lippincott Williams & Wilkins.

Fry A. C. (2004). The role of resistance exercise intensity on muscle fibre adaptations. *Sports Medicine*, *34*, 663–679.

Garcia-Pallares J., Sanchez-Medina L., Perez C. E., Izquierdo-Gabarren M., & Izquierdo M. (2010). Physiological effects of tapering and detraining in world-class kayakers. *Medicine and Science Sports and Exercise*, *42*, 1209–1214.

González-Badillo J. J., Marques M. C., & Sánchez-Medina L. (2011). The importance of movement velocity as a measure to control resistance training intensity. *Journal of Human Kinetics*, *29A*, 15–19.

González-Badillo J. J., Rodríguez-Rosell D., Sánchez-Medina L., Gorostiaga E. M., & Pareja-Blanco F. (2014). Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training. *European Journal of Sport Science*, *14*(8), 772–781.

González-Badillo J. J., & Sánchez-Medina L. (2010). Movement velocity as a measure of loading intensity in resistance training. *International Journal of Sports Medicine*, *31*, 347–352.

Hasegawa H. (2010). A real time feedback and monitoring of speed and power in resistance training for athletes. In: H. Dusan ed. 7th International Congress on Strength Training Abstracts. Bratislava, 51–54.

Hatfield D. L., Kraemer W. J., Spiering B. A., Häkkinen K., Volek J. S., Shimano T., … Maresh C. M. (2006). The impact of velocity of movement on performance factors in resistance exercise. *Journal of Strength Conditioning Research*, *20*(4), 760–766.

Hill A. V. (1938). The heat of shortening and the dynamics constants of muscle. *Proceedings of Royal Society London Serv. B*, *126*(843), 136–195.

Ingebrigtsen J., Holtermann A., & Roeleveld K. (2009). Effects of load and contraction velocity during three-week biceps curls training on isometric and isokinetic performance. *Journal of Strength and Conditioning Research*, *23*(6), 1670–1676.

Jidovtseff B., Croisier J., Scimar N., Demoulin C., Maquet D., & Crielaard J. (2008). The ability of isoinertial assessment to monitor specific training effects. *Journal of Sports Medicine and Physical Fitness*, *48*, 55–64.

Jidovtseff B., Harris N. K., Crielaard J.-M., & Cronin J. B. (2011). Using the load-velocity relationship for 1RM prediction. *Journal of Strength and Conditioning Research*, *25*, 267–270.

Jones K., Hunter G., Fleisig G., Escamilla R., & Lemak L. (1999). The effects of compensatory acceleration on upper-body strength and power in collegiate football players. *Journal of Strength and Conditioning Research*, *13*, 99–105.

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

Mayhew J. L., Prinster J. L., Ware J. S., Zimmer D. L., Arabas J. R., & Bemben M. G. (1995). Muscular endurance repetitions to predict bench press strength in men of different training levels. *Journal of Sports Medicine and Physical Fitness*, *35*, 108–113.

Mayhew J. L., Ware J. S., Cannon K., Corbett S., Chapman P. P., Bemben M. G., … Slovak J. P. (2002). Validation of the NFL-225 test for predicting 1-RM bench press performance in college football players. *Journal of Sports Medicine and Physical Fitness*, *42*, 304–308.

Pallarés J. G., Sánchez-Medina L., Pérez C. E., De La Cruz-Sánchez E., & Mora-Rodriguez R. (2014). Imposing a pause between the eccentric and concentric phases increases the reliability of isoinertial strength assessments. *Journal of Sports Sciences*, *32*(12), 1165–1175.

Pereira M. I., & Gomes P. S. (2003). Movement velocity in resistance training. *Sports Medicine*, *33*, 427–438.

Randell A. D., Cronin J. B., Keogh J. W. L., Gill N. D., & Pedersen M. C. (2011). Effect of instantaneous performance feedback during 6 weeks of velocity-based resistance training on sport specific performance tests. *Journal of Strength and Conditioning Research*, *25*(1), 87–93.

Reilly T., Morris T., & Whyte G. (2009). The specificity of training prescription and physiological assessment: A review. *Journal of Sports Sciences*, *27*(6), 575–589.

Reynolds J. M., Gordon T. J., & Robergs R. A. (2006). Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *Journal Strength and Conditioning Research*, *20*, 584–592.

Rontu J.-P., Hannula M. I., Leskinen S., Linnamo V., & Salmi J. A. (2010). One-repetition maximum bench press performance estimated with a new accelerometer method. *Journal of Strength and Conditioning Research*, *24*, 2018–2025.

Sakamoto A., & Sinclair P. J. (2012). Muscle activations under varying lifting speeds and intensities during bench press. *European Journal of Applied Physiology*, *112*, 1015–1025.

Sánchez-Medina L., & González-Badillo J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine & Science in Sports & Exercise*, *43*, 1725–1734.

Sanchez-Medina L., Perez C. E., & Gonzalez-Badillo J. J. (2010). Importance of the propulsive phase in strength assessment. *International Journal of Sports Medicine*, *31*, 123–129.