Researched applications of velocity based strength training. J. Aust. Strength Cond. 22(2)58-69. 2014 © ASCA.

From the Field

RESEARCHED APPLICATIONS OF VELOCITY BASED STRENGTH TRAINING

Mladen Jovanović[1] & Dr Eamonn P. Flanagan[2]

[1]Hammarby Fotboll AB / Hammarby IF Fotbollförening Veterinärgränd 6 121 63 Johanneshov Sweden.
[2]Irish Rugby Football Union, 10-12 Lansdowne Road, Dublin 4, Ireland.

ABSTRACT

Strength training is a critical exercise stimulus for inducing changes in muscular strength, size and power (6). Recently, linear position transducers have gained in popularity as a means to monitor velocity in strength training exercises. The measurement error of such devices has been shown to be low and both relative and absolute reliability have been shown to be acceptable (2, 7, 11). The purpose of this article is to provide the overview and benefits of monitoring movement velocity in strength training exercises, along with providing the basis for novel "velocity-based" strength training prescription. We have covered the following practical applications: Guidelines to develop a velocity/load profile for athletes; Using the velocity load/profile to predict and monitor changes to maximal strength; Using velocity monitoring to control fatigue effects of strength training; Using velocity monitoring as an immediate performance feedback to promote the highest level of effort in specific training exercises and stronger adaptive stimuli. Linear position transducers are reliable and valid tools to help strength and conditioning practitioners monitor and optimize their strength training programs.

Keywords – Strength, velocity, bench press, squat, linear position transducer.

INTRODUCTION

Strength training is a critical exercise stimulus for inducing changes in muscular strength, size and power (6). Traditionally, several acute training variables have been identified and utilized for strength training program design and prescription: exercise type and order, intensity or load, number of repetitions and sets, and rests between sets (10, 18). Manipulation of these variables shapes the magnitude and type of physiological responses and, ultimately, the adaptations to strength training (6, 10, 18).

Exercise intensity or load is generally acknowledged as the most important stimulus related to changes in strength levels and has been commonly identified with relative load (percentage of one-repetition maximum, % of 1RM) (6, 10). This approach, named "traditional" or "percent-based" in the current article, requires coaches to individually assess the 1RM values for each athlete and each core exercise utilized in the training program. In practice this is usually done by direct 1RM assessment, or performing reps to failure with submaximal loads. With the former method, coaches and athletes utilize various established tables (repetition maximum continuum) to estimate 1RM from the load and number of reps being performed.

When 1RMs for each athlete's core exercises are known, coaches proceed with training program design utilizing percent-based prescription. This traditional approach in strength training prescription revolves around prescribing relative loads (% of 1RMs) and utilizing established 1RMs to calculate the absolute weight that needs to be lifted for a given number of reps and sets.

This traditional approach has multiple shortcomings in practical settings. Direct assessment of 1RM may be associated with injury when performed incorrectly or by novice athletes and it is time consuming and impractical for large groups (10). Furthermore, the actual 1RM can change quite rapidly after only a few training sessions, especially with novice athletes, and often the obtained values are not the athletes' true maximum (10). This also involve changes in day-to-day readiness that are caused by a normal biological variability, training related fatigue or life-style factors, like sleep, stress and nutrition. Utilizing 1RMs that were estimated before the training program commenced will not take this into account. Additionally, changes in 1RM might not reflect the whole changes taking places along the load/velocity continuum. Hence, it is important for coaches and researches to monitor and report changes in load/velocity profiles alongside changes in 1RM values.

The aforementioned limitations suggest trying to find better ways to objectively monitor training load during resistance exercise (10). Movement velocity is another variable which should be of interest for monitoring exercise intensity but it has been vaguely mentioned in most studies (10). The lack of use of this variable is likely because until recently it was not possible to accurately measure velocity in typical strength training exercises (10).

Therefore, the purpose of this article is to provide the overview and benefits of monitoring movement velocity in strength training exercises, along with providing the basis for novel "velocity-based" strength training prescription.

Clarifying exercise terminology

To provide clarity in terminology used, in the current article we utilize the following components of "intensity" in strength training.

The term "**load**" relates to the weight the athlete is lifting in a given exercise expressed as the percentage of the known 1RM (% of 1RM), e.g., if an athlete is performing bench press with 100kg, and the known 1RM is 110kg, then the load is 90%.

The term "**effort**" relates to the athlete's intent to perform a repetition of a given exercise with maximum possible acceleration and speed in the concentric phase. In the current article we assume maximal effort expressed by the athlete for each repetition in the set unless otherwise stated.

The term "**exertion**" is related to the proximity of failure in a given set. It seems reasonable that the degree or level of exertion is substantially different when performing, e.g., 8 of 12 possible repetitions (12RM) with a given load (8[12]) compared with performing maximum number of repetitions (12[12]) (18). Exertion, in strength coaches' jargon, is usually expressed as "reps left in the tank". Using the previous example, performing 8 reps with 12RM load represents submaximal exertion with 4 reps left in the tank. Performing 12 reps with 12RM represents maximal exertion with no reps left in the tank.

LINEAR POSITION TRANSDUCERS (LPT)

The velocity of lifting can now be easily and reliably measured in many basic strength training exercises using commercially available linear position transducers (LPT) (12). These devices typically take the form of a central processing unit that attaches to the resistance training equipment (such as a barbell) via a retractable, measuring cable (12). LPT devices convert physical attributes (the length of the measuring cable) into electrical signals to yield the displacement of an object, in this case the barbell, other resistance training equipment or the athletes themselves. Velocity can then be calculated from the displacement and time [*velocity = displacement (d) / time (t)*]. Acceleration can then be calculated from changes in velocity over time [*acceleration = velocity (v) / time (t)*] (12).

LPT devices display live, velocity-based feedback via a display screen or via a secondary device (such as personal computer or tablet device). The measurement error of such devices has been shown to be very low and both relative and absolute reliability have been shown to be acceptable (2, 7, 11). A comprehensive review of the technology underpinning this equipment is available (12).

When measuring velocity during basic non-ballistic strength training exercises such as the bench press or the squat, Jidovtseff et al. (14) has suggested measuring mean concentric velocity and not peak concentric velocity. Mean velocity is seen to better represent the ability of the athlete to move the load through the entire concentric phase (14). In the current article, the term "velocity" refers to the mean concentric velocity unless otherwise stated.

Training with the intention to move the load with the highest effort is believed to drive adaptations to training and is important during strength training designed to improve power output regardless of contraction type, load or actual/absolute movement velocity of the exercises (1, 5, 6). A number of thorough reviews of the relevant literature have been presented by different authors and it is suggested that there is also a velocity specific response to training (5, 6). Velocity specific improvements in strength and power are more likely elicited by utilizing that actual movement velocity in training (5, 6). Therefore the intention to move the load with the highest effort and the actual movement velocity are both vital stimuli required to drive and optimize adaptation (5). Linear position transducers can assist coaches and athletes in achieving both of these training goals. Regardless of the load being lifted, LPTs provide athletes with immediate feedback on actual movement velocity, which can help encourage them to attempt to express maximal effort. The direct measurement of velocity also allows coaches to optimize and monitor velocity specific training. It has also been shown that providing immediate real-time performance feedback (such as peak velocity) for jump squats yields higher consistency between sessions (17) and greater adaptation and larger training effects to non-feedback training (16).

DEVELOPING A LOAD/VELOCITY PROFILE

The LPT can be used to develop a "load/velocity" profile for an athlete in a particular exercise. There exists an inextricable relationship between load and velocity that can allow practitioners to use one to estimate the other. The velocity of concentric muscle action decreases with increasing force output and with increasing load (8, 10, 14, 19).

To establish the load/velocity profile the athlete performs repetitions at a number of pre-determined relative or absolute loads. Having assessed the available published research and from our own practical experience we recommend measuring mean concentric velocity over at least 4-6 increasing intensities of load ranging from 30-85% of actual or estimated 1RM. Along with other authors, we recommend at least 3 minutes of passive recovery between sets (3). It is suggested a large enough "spread" of loading should be used to ensure a decrease in velocity of 0.5m/s between the lightest and heaviest loads (14). It has been recommend in the research to perform 3 reps at lighter loads (where velocity > 1.0m/s), 2 reps at moderate loads (0.65 – 1.0 m/s) and 1 rep at heavy loads (<0.65m/s) (19). The highest velocity recorded at each load is included in the analysis of the load/velocity profile (19).

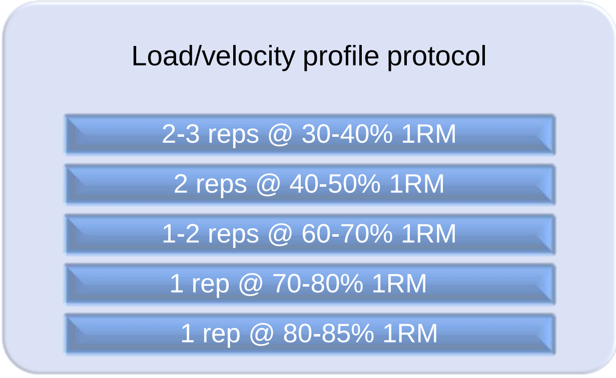

Figure 1 - Example load/velocity profile protocol for bench press.

When conducting this procedure athletes must be instructed to express maximal effort on every repetition regardless of the load being lifted. With lighter loads (<50% 1RM) our observations have been that lifting technique may be altered, so coaches should encourage athletes to maintain consistent technique across load ranges.

An example of an athlete's load/velocity profile in the bench press exercise can be seen in Figure 2 where the load (% 1RM) is plotted on the x-axis and the achieved velocity is plotted on the y-axis.

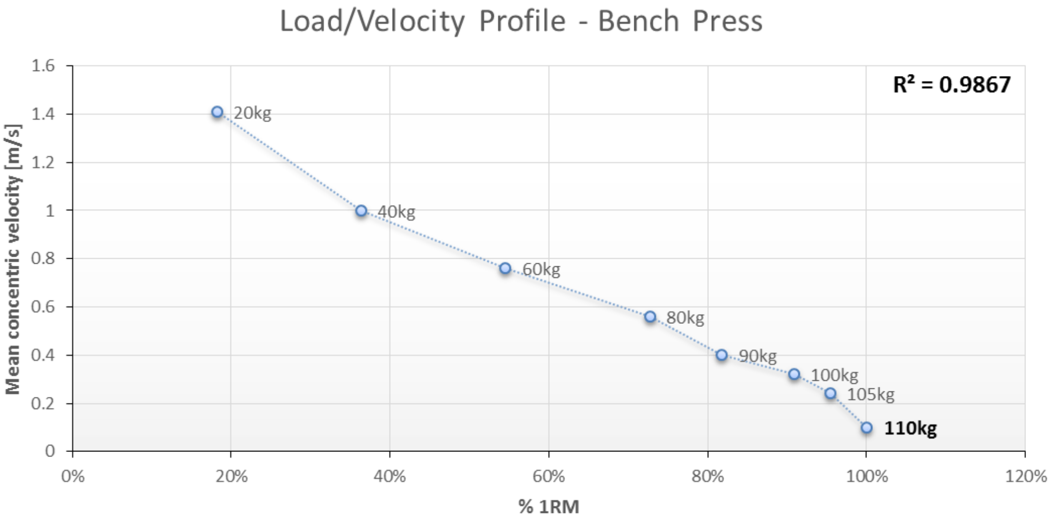

Figure 2 - Example load/velocity profile for bench press. Mean concentric velocity values (m/s) are displayed on the graph. Load is expressed as % 1RM. The athlete's 1RM is 110kg.

Table 1 - The raw data used to generate Figure 2, where MV = mean concentric velocity.

1RM	110	
Load (kg)	%1RM	MV (m/s)
20	18%	1.41
40	36%	1
60	55%	0.76
80	73%	0.56
90	82%	0.4
100	91%	0.32
105	95%	0.24
110	100%	0.1

Research has shown a very strong relationship between velocity and load (3, 10, 14, 18, 19). The relationship between load and velocity can be described by simple linear regression that yields slope and intercept of the line. The strength of this relationship can be described by the correlation coefficient (r), coefficient of determination (R^2), or standard error of the estimate (SEE) (20). Standard Error of the Estimate (SEE) is the measure of the accuracy of predictions (20). All of these statistics are easily calculated via common spreadsheet software programs.

Badillo and Sanchez-Medina (10) reported a very strong relationship between velocity and load when fitted with a 2nd order polynomial regression, with individual curve fits giving an R^2 ranging from 0.993 to 0.999. Anecdotally, our own work in professional rugby and football have shown linear regressions to also be very well fitted to load/velocity profiles and with R^2 values of >0.95 commonly observed. Other published research has also used linear regression for load/velocity profiles (3).

Practitioners should note that the more data points tested, the stronger the predicted relationship via regression analysis (20). While some authors have used a fifteen point test protocol with repetitions performed at every 5% interval from 30—100% of 1RM (10); such an extensive assessment of the load/velocity profile is often not feasible in the practical domain where there can be limited training time and conflicting training demands.

While we recommend using 4-6 different intensities of load ranging from 30-85% of 1RM (or estimated/predicted 1RM), coaches should assess what testing protocol works best for them in the context of their athlete group and training demands. When comparing load/velocity profiles over time, practitioners should try to keep the same or similar protocol of testing to maximize reliability of estimates.

Creating a load/velocity profile in an identified key training exercise allows coaches the opportunity to track an athlete’s progress, over time, across a spectrum of velocity demands. This is particularly applicable for coaches who are interested in velocity specific adaptation to training and not solely focused on maximal strength development. Creating a load/velocity profile also allows coaches to compare athletes against each other across the velocity spectrum. Load/velocity profiling can also be used to predict 1RM values using sub-maximal loads. This may be of great interest to coaches and athletes if true maximal testing is not viable or appropriate. Measuring velocity with sub-maximal loads during sessions allows coaches to estimate daily 1RM values which can be used to assess the efficacy of training programs and the training status of the athlete.

MINIMAL VELOCITY THRESHOLD (MVT)

As can be seen from the Figure 2 and Table 1, maximal load (1RM) attempts are associated with a specific velocity that is termed “1RM velocity” or the “minimal velocity threshold (MVT)”. The MVT is the mean concentric velocity produced on the last successful repetition of a set to failure performed with maximal lifting effort. MVT has been shown to be exercise specific with approximate mean concentric velocities of 0.15 m/s for bench press and 0.30 m/s for back squat being reported (10, 13) (see Figure 3).

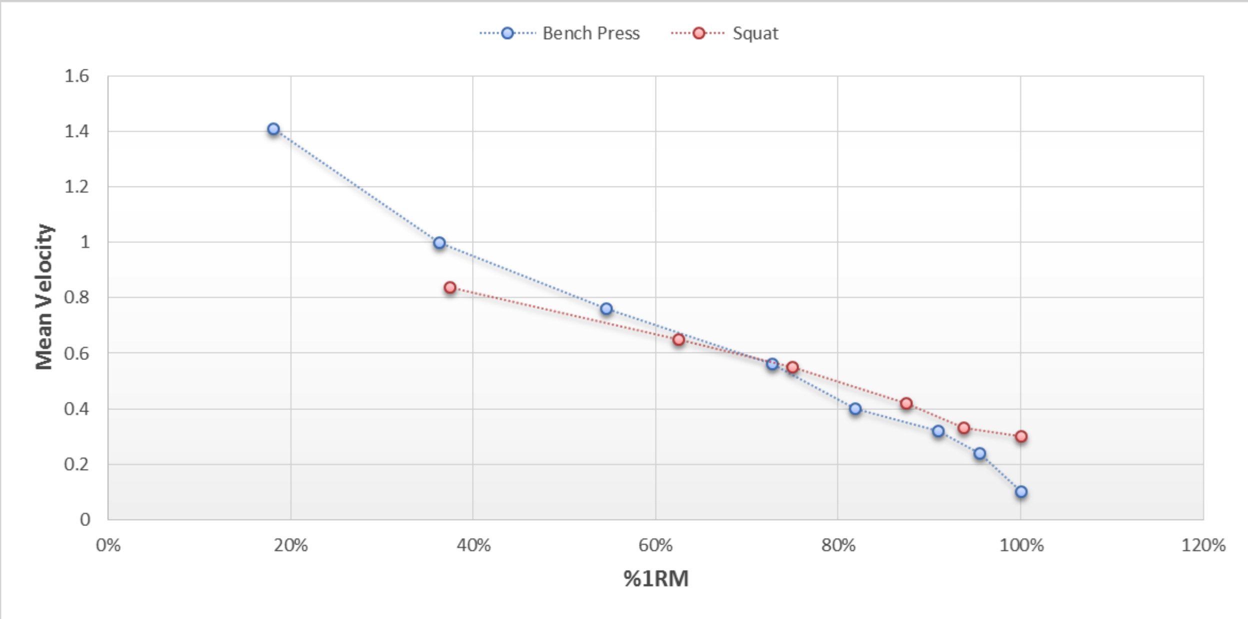

Figure 3 - Different load/velocity profiles for bench press and squat for a single individual. Note the different velocities at 1RM load (MVT).

There appears to be no statistical differences between velocity in 1RM attempts and velocity produced on the last successful repetition in sets to failure at sub-maximal loads. Izquierdo et al. (13) had subjects perform repetitions to failure in both the bench press and the half squat exercises at a range of sub-maximal loads: 60%, 65%, 70% and 75% of 1RM with maximal effort. In this study, no significant differences were seen in MVT regardless of relative load or number of repetitions per set to failure.

The range of repetitions per set was from 17 (±2) reps at 60% 1RM to 9 (±2) reps at 75% 1RM in the bench press exercise. The MVT across the 4 fatigue protocols in the bench press exercise was 0.175 (±0.05) m/s. There were also no statistically significant differences observed between MVT in the sub-maximal sets to failure and MVT observed in true 1RM attempts (0.15 ±0.05) m/s. Other authors have also demonstrated similar MVT values in 1RM bench press testing of 0.16 (±0.04) m/s (10).

Izqueirdo et al. (13) observed the same trends in MVT in the parallel squat exercise: there were no statistically significant differences observed between MVT in the sub-maximal sets to failure and MVT observed in true 1RM half squat attempts. However the MVT values observed were significantly different between exercises. The MVT across the 4 fatigue protocols in the parallel squat exercise was 0.32 (±0.06) m/s and in 1RM testing was 0.27 (±0.06) m/s.

The MVT of an exercise also appears to remain stable when absolute maximal strength increases (10). Research by González-Badillo and Sánchez-Medina (10) observed significant increases in maximal strength in the bench press exercises after a 6-week training period but mean concentric velocity at that relative 1RM load did not change with training. This suggests that there appears to be a stable, exercise specific MVT required to make successful reps regardless of intensity of load or number of repetitions performed per set. This observation opens up a number of practical inferences for coaches.

Athletes' MVT for a particular exercise such as bench press can be individually assessed using either 1RM test or a set to failure with a submaximal load. Research suggests that the exact percentage load to be used in this assessment can be left to the coach's discretion. A load, which is likely to elicit a number of repetitions relevant to the current training phase, can be selected. The individual athlete's MVT is assessed as the mean concentric velocity on their last complete repetition before failure. Figure 4 demonstrates an example of such a protocol. The athlete in question performs repetitions to failure with approximately 75% of his 1RM and produces an MVT of 0.1m/s. While a high rep protocol was used here, a higher load (and resultantly less repetitions) could also be used.

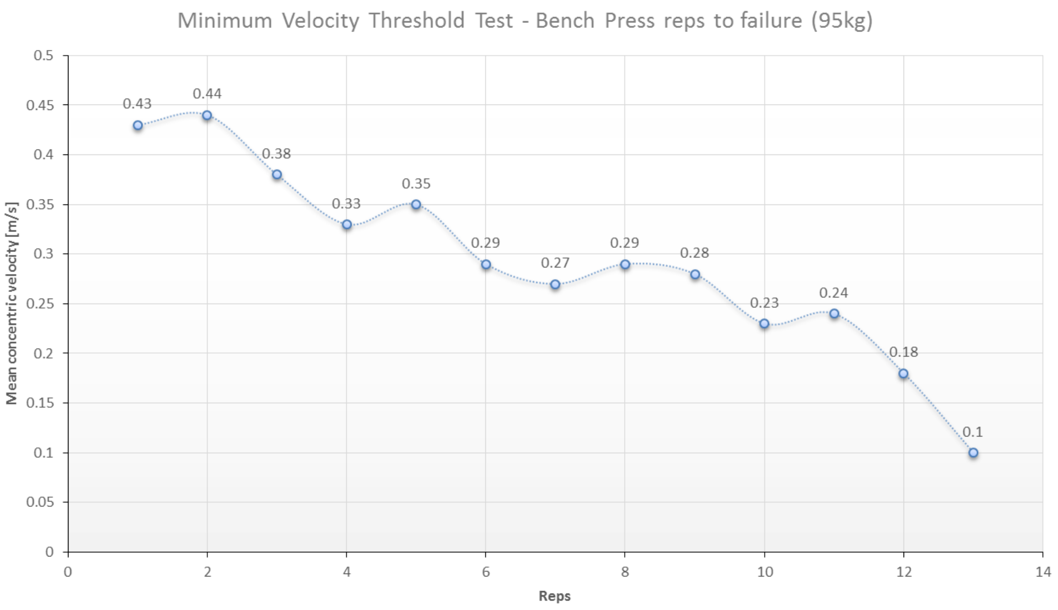

Figure 4 - A repetitions to failure protocol can identify an athlete's minimum velocity threshold for a specific exercise.

This individualized MVT becomes a key piece of information for coaches. One application is using it to assess if 1RM testing reps are true maximums or not. Some authors have suggested only considering a true 1RM effort for those lifts whose mean concentric velocity is less than 0.2 m/s, assuming maximal effort on every repetition. Having such a threshold can help coaches make informed decisions on whether or not to push athletes towards additional attempts on 1RM testing days.

EXERTION/VELOCITY PROFILE

As previously explained, the study by Izquierdo et al. (13) looked at velocities of individual reps in the sets performed to failure at 60%, 65%, 70% and 75% of 1RM with maximal effort. Since MVT for a given exercise is not statistically different between 1RM and the last rep in a set to failure, we wished to assess if the velocities were similar between same exertion level expressed as “reps in the tank” (number of reps shy of failure) across different loads (% of 1RM used).
By digitalizing figures from Izquierdo et al. (13) and reorganizing data we were able to gain additional insights. In the Table 2 and Table 3 is the data for squat on the Figure 4 there is graphical representation of the data.

Table 2 - Digitalized data for squat from Izquierdo et al. (13).

60% 1RM			65% 1RM			70% 1RM			75% 1RM		
Rep	MV	Reps in tank	Rep	MV	Reps in tank	Rep	MV	Reps in tank	Rep	MV	Reps in tank
1	0.61	20	1	0.55	16	1	0.51	12	1	0.49	9
2	0.58	19	2	0.55	15	2	0.51	11	2	0.49	8
3	0.57	18	3	0.53	14	3	0.50	10	3	0.47	7
4	0.58	17	4	0.53	13	4	0.50	9	4	0.45	6
5	0.57	16	5	0.52	12	5	0.47	8	5	0.44	5
6	0.56	15	6	0.52	11	6	0.48	7	6	0.42	4
7	0.55	14	7	0.51	10	7	0.46	6	7	0.41	3
8	0.54	13	8	0.51	9	8	0.46	5	8	0.39	2
9	0.55	12	9	0.51	8	9	0.45	4	9	0.38	1
10	0.53	11	10	0.50	7	10	0.43	3	10	0.31	0
11	0.53	10	11	0.48	6	11	0.43	2			
12	0.54	9	12	0.47	5	12	0.44	1			
13	0.52	8	13	0.46	4	13	0.33	0			
14	0.50	7	14	0.43	3						
15	0.48	6	15	0.44	2						
16	0.49	5	16	0.40	1						
17	0.47	4	17	0.32	0						
18	0.47	3									
19	0.44	2									
20	0.39	1									
21	0.34	0									

Table 3 - Reorganized data for squat from Izquierdo et al. (13). Velocity for each rep is organized based on load used and exertion level expressed as reps shy of failure ("reps in the tank").

Reps in tank	60%	65%	70%	75%	Average	SD	%CV
9	0.54	0.51	0.50	0.49	0.51	0.02	4%
8	0.52	0.51	0.47	0.49	0.49	0.02	4%
7	0.50	0.50	0.48	0.47	0.49	0.02	4%
6	0.48	0.48	0.46	0.45	0.47	0.01	3%
5	0.49	0.47	0.46	0.44	0.46	0.02	5%
4	0.47	0.46	0.45	0.42	0.45	0.02	5%
3	0.47	0.43	0.43	0.41	0.43	0.02	5%
2	0.44	0.44	0.43	0.39	0.42	0.02	6%
1	0.39	0.40	0.44	0.38	0.40	0.02	6%
0	0.34	0.32	0.33	0.31	0.32	0.01	3%

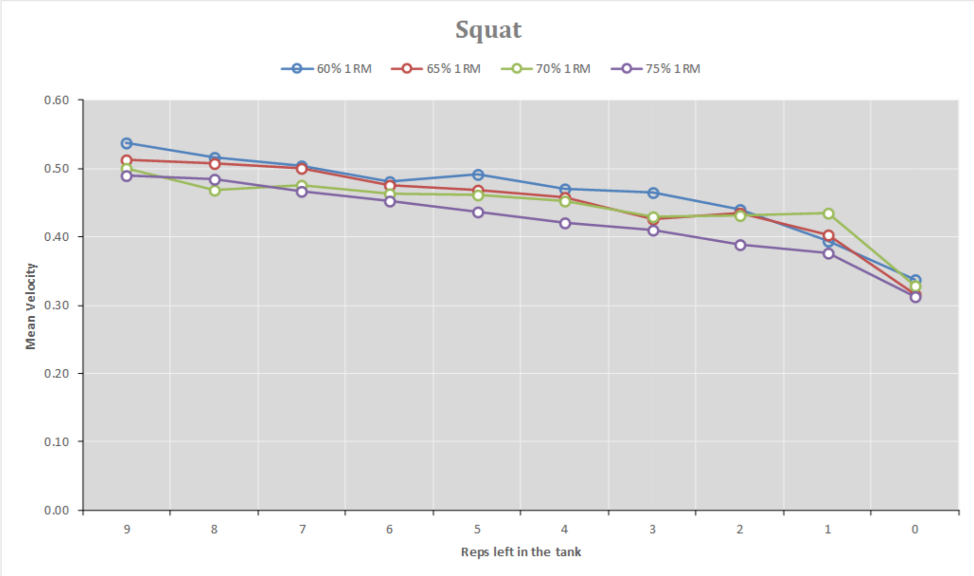

Figure 5 - Chart done using digitalized and reorganized data from Izquierdo et al. (13).

What is insightful from this way of presenting data is that regardless of the load being used (% of 1RM), velocities at the same exertion level (rep left in the tank) are very similar (CV from 3 to 6%). The practical significance of this is that by monitoring repetition velocities during the set (assuming maximal effort) one can estimate the proximity of failure and exertion expressed by the athlete for a given set. Along with MVT, this observation opens up a number of practical inferences for coaches. Exertion/velocity profile could be created for a single individual and exercise by combining load/velocity profile, MVT and repetitions to failure protocol or by using established repetition maximum tables.

PRACTICAL APPLICATIONS

Understanding load/velocity profile, minimal velocity threshold (MVT) and exertion/load profile are crucial in applying velocity-based strength training. Application of velocity-based approach doesn't involve all-or-nothing implementation, where you either use traditional percent-based or novel velocity-based approach. Contrary to that, velocity-based approach involves different levels of implementation that could be used together with a traditional approach as a way to overcome its shortcomings. In the current article we are going to present a couple of such implementations of velocity-based approach and velocity monitoring in strength training.

Practical application 1 - Comparing individuals using load/velocity profile and monitoring changes over time

Creating a load/velocity profile in an identified key training exercise allows coaches the opportunity to track an athlete's progress, over time, across a spectrum of velocity demands. This is particularly applicable for coaches who are interested in velocity specific adaptation to training and not solely focused on maximal strength development. Creating a load/velocity profile also allows coaches to compare athletes against each other across the velocity spectrum, instead of only using 1RM. Figure 6 demonstrates such a comparison. Both athletes are high-level rugby union players, playing in the same position with a similar bench press 1RM of approximately 125kg. Of the two players, player 2 demonstrates higher velocities at sub-maximal loads, suggesting he has greater velocity characteristics, which might yield additional transfer to athletic performance. This observation is not possible with measuring 1RM solely.

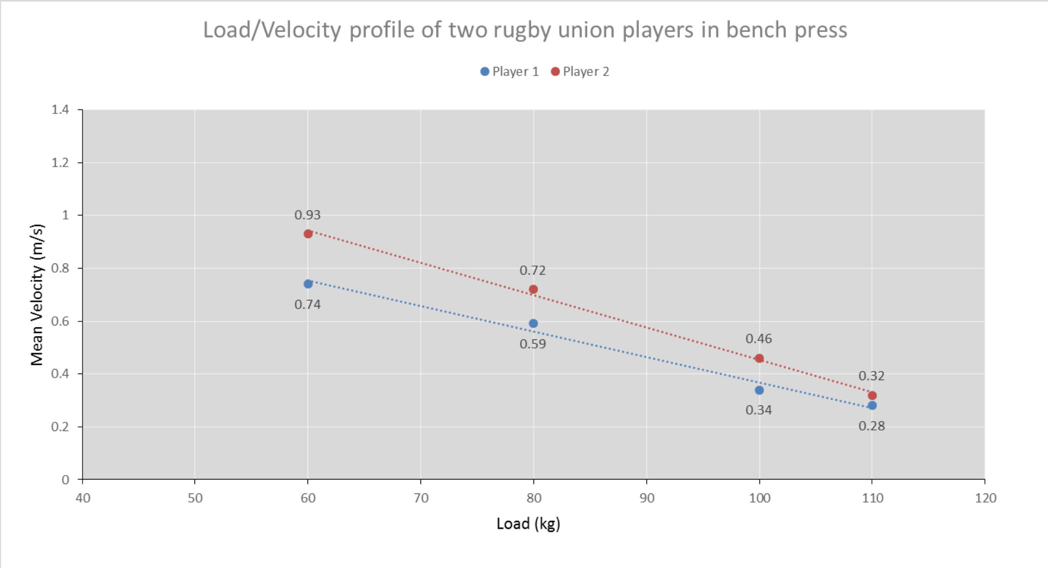

Figure 6 - The difference in load/velocity profile of two rugby union players with same 1RM (approx. 125kg) in bench press.

Having a load/velocity profile might inform training decisions such as spending more time in developing power or velocity specific characteristics rather than maximal strength with certain athletes, or vice versa. By monitoring an athlete's load/velocity profile over time, coaches can measure velocity specific adaptations to training and assess if the training program is improving adaptation holistically across the whole velocity/load spectrum.

Practical application 2 - Estimating 1RM from sub-maximal loads.

We have recommend measuring mean concentric velocity at 4-6 increasing intensities of load ranging from 30-85% of actual or estimated 1RM to estimate load/velocity profile. To estimate 1RM for an individual, coaches need to know the MVT of the exercise which could be assessed through traditional 1RM test or reps to failure test. Once the MVT is known for a given exercise and individual, traditional 1RM tests could be repeated only occasionally to test the real changes in 1RM. Because of the high stability of MVT across time (10) one could reliably use sub-maximal testing to estimate 1RM.

Using velocities from sub-maximal loads and known MVT, regression equation of the line can be used to predict or estimate current 1RM strength levels. If individual MVTs are not known, coaches can use 0,15m/s for bench press and 0,3m/s for squat as a general rule of thumb (13).

The equation of the line takes the following format (20)

Load = *m*(Velocity) + *b* $\pm$ **Z(SEE)**

Where, *m* is the slope of the line *b* is the intercept Z represents the desired level of confidence (LOC) where 1.645 is used for a 90% LOC and 1.96 is used for a 95% LOC (20)
SEE is the standard error of the estimate

Using the data from the Table 1 and entering it into a spreadsheet software application, such as Microsoft Excel, we can calculate the slope, intercept and SEE of the load/velocity relationship for the bench press (or squat).

	C	D	E	F	G
1	1RM	110			
2	Load (kg)	%1RM	MV (m/s)		
3	20	18%	1.41		
4	40	36%	1		
5	60	55%	0.76		
6	80	73%	0.56		
7	90	82%	0.4		
8	100	91%	0.32		
9	105	95%	0.24		
10	110	100%	0.1		
11					
12	Slope	-74.1	=SLOPE(C3:C10; E3:E10)		
13	Intercept	120.0	=INTERCEPT(C3:C10; E3:E10)		
14	SEE	4.1	=STEYX(C3:C10; E3:E10)		

Figure 7 - Calculating Slope, Intercept and SEE of load/velocity profile in Microsoft Excel. Formulas are shown in column E. Data is taken from Table 1.

Using these parameters one can estimate 1RM using a known MVT for a given exercise and individual. Using the data from Table 1 we can estimate 1RM at 0.15m/s (MVT for bench press):

Load = *m*(Velocity) + *b* ± Z(SEE)
Load = -74.1 x 0.15 + *120* ± Z(SEE)
Load = 108.9 ± Z(SEE)

Calculated 1RM using a known MVT (0,15m/s) is 108.9 kg in this case. As can be seen from the Table 1, the “real” 1RM is 110kg which is around 1% difference and not practically significant.

In Microsoft Excel the trend function (“=TREND”) can be used to calculate this estimation.

	C	D	E	F	G
1	1RM	110			
2	Load (kg)	%1RM	MV (m/s)		
3	20	18%	1.41		
4	40	36%	1		
5	60	55%	0.76		
6	80	73%	0.56		
7	90	82%	0.4		
8	100	91%	0.32		
9	105	95%	0.24		
10	110	100%	0.1		
11					
12	Slope	-74.1	=SLOPE(C3:C10; E3:E10)		
13	Intercept	120.0	=INTERCEPT(C3:C10; E3:E10)		
14	SEE	4.1	=STEYX(C3:C10; E3:E10)		
15	MVT	0.15			
16	ets1RM	108.9	=TREND(C3:C10; E3:E10; D15)		
17					

Figure 8 - Estimating 1RM (est1RM) from load/velocity profile using MVT in Microsoft Excel. Data is from Table 1.

To add confidence intervals for this estimate, the SEE can be calculated from the linear regression. For a 90% level of confidence, the SEE is multiplied by 1.645 (20). An example of how this calculation is conducted is as follows:

Load = 108.9 ± Z(SEE)
Load = 108.9 ± 1.645 x 4.1
Load = 108.9 ± 6.7 kg
Load = 102.2 to 115.6kg [90% LOC]

As stated previously, SEE represents the measure of the accuracy of predictions. In the case of tracking estimated 1RMs for predicting and monitoring changes in maximal strength for a single individual over time, confidence intervals calculated from SEE could be visualized using error bars on the graph (see Figure 8).

Using SEE allows us to assess the accuracy of our estimates. With lower SEE we get better predictions for the estimates of 1RM. For traditional exercises like bench press and squat used with free weights or guided barbells (smith machine) the use of load/velocity relationship to predict the 1RM appears accurate (14) and is highly correlated with actual 1RM (3). However, some studies have high correlations but with largely different 1RM values (3). Considering this, the 1RM estimated from the submaximal load/velocity profile is an appropriate measure to monitor training induced adaptations (3). However, our recommendation is that actual 1RM and predicted 1RM values are not used interchangeably and the predicted values from the load/velocity protocol should only be compared to themselves to monitor progress. It still important to occasionally perform traditional 1RM test to verify the changes evaluated using estimated 1RM.

This is not the only method by which to monitor training induced adaptation via the load/velocity profile. According to González-Badillo et al. (10) if velocity at a given absolute load improves by more than 0.07 – 0.09 m/s, this corresponds to an improvement in 1RM of approximately 5%. While this will be dependent on some inherent characteristics of the athlete in question, from our experience in professional team sports (rugby, football) this is a good general approximation to assess how changes in velocity characteristics may affect maximal strength characteristics.

Practical application 3 - Estimating daily readiness or daily 1RM.
Using an abbreviated version of 1RM estimation, in this case using 3-4 progressive warm-up sets, coaches are able to quickly estimate daily readiness or daily 1RM without interfering with the prescribed training session.

Figure 9 visualizes the estimated 1RMs from warm-up sets in the squat over the duration of a training block. This training block was a novel high-frequency block for an athlete which he was not accustomed to. Error bars represent 90% confidence intervals for the estimated 1RM. Dotted line represent pre-training block 1RM used to prescribe weights for the squat using traditional approach (% 1RM). The 1RM was tested couple of weeks preceding the beginning of high-frequency block and might have been lower than 1RM at the beginning of the training block. As explained in the introduction section of the current article, this represents one of the shortcomings of the traditional approach.

As can be seen from Figure 9, daily estimated 1RMs tend to be different from the pre-training block 1RM. Estimating daily 1RMs is very useful in monitoring changes in maximum strength, but it could also be used to prescribe daily weights taking into account daily variability in maximum strength, instead of relying on pre training block 1RM numbers.

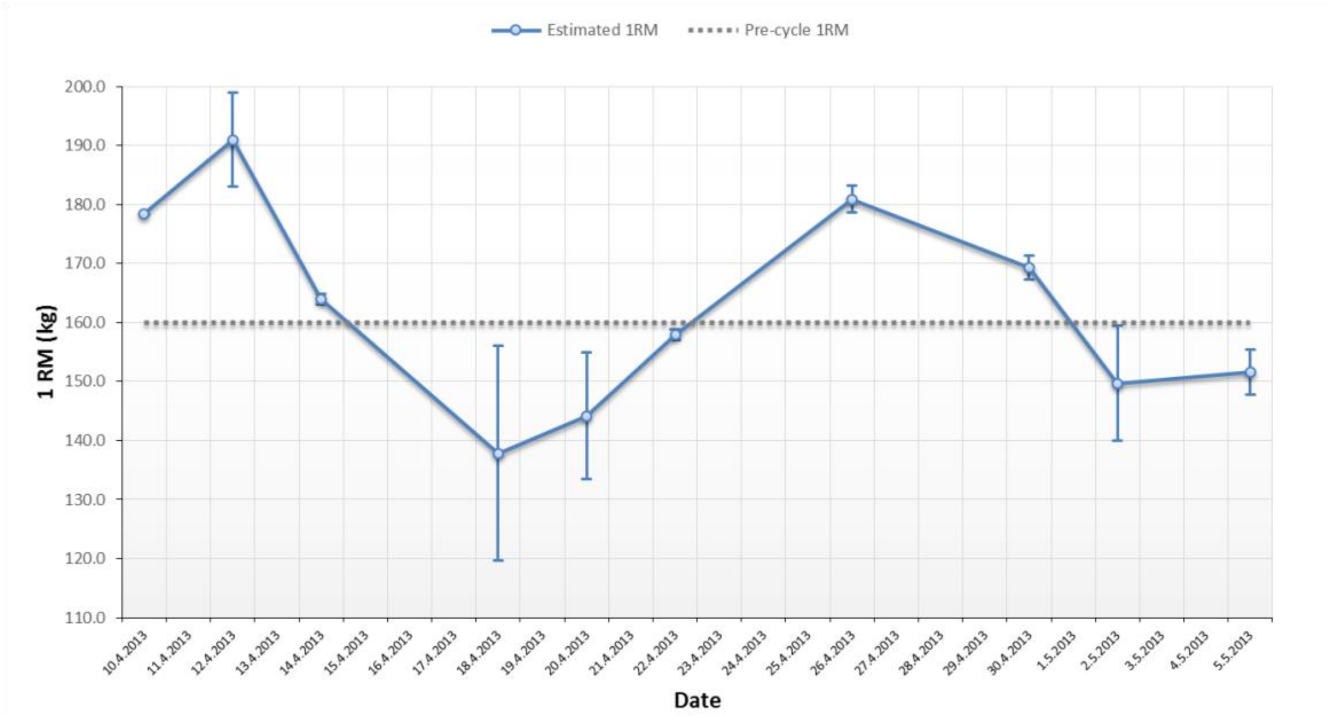

Figure 9 - Estimating 1RMs from warm-up sets for the squat over duration of the training block. Dotted line represent pre-cycle 1RM use to plan training weights. Error bars represent 90% confidence intervals.

Using regular (daily or weekly) estimated 1RMs may help coaches to adjust workouts if percentages of 1RM are used to program training load. This approach would allow coaches to assess day-to-day variability in training readiness and adjust training plans accordingly.

This estimated 1RM from load-velocity regression during warm-up sets could be used to control the training process through mathematical modelling (4) and provide individualized periodization approach to allow optimal loading and peaking strategies. Further research using this approach for mathematical modelling is warranted.

Practical Application 4 - Using velocity monitoring and exertion/velocity profile to control fatigue and exertion
Velocity monitoring can be used to limit the amount of metabolic by-product accumulation incurred during resistance training sets. Research has demonstrated that by monitoring repetition velocity during training it is possible to reasonably estimate the metabolic stress induced by resistance training (18). Velocity naturally slows during a set of repetitions as fatigue develops (3, 13, 14, 18) (see Figures 4 and 5).

Strong relationships have been observed between velocity loss during lifting and metabolic measures of fatigue (18). Research has shown that post-exercise lactate concentration linearly increases as the number of performed repetitions in each set approaches a maximum (18). Increases in ammonia concentrations follow a curvilinear trend in relation to velocity loss. From a velocity loss of approximately 35% (of initial velocity) in the bench press and 30% in the squat exercise, blood ammonia levels started to increase steadily above resting levels. Significant rises in ammonia are associated with accelerated purine nucleotide degradation, which necessitates longer recovery times (18).

The gradual decrease in repetition velocity that occurs during resistance training sets can be interpreted as evidence of impaired neuromuscular function (13, 18). Its measurement affords coaches and athletes a simple means of controlling the extent of fatigue. This could be done by prescribing “velocity stops” for each set. Velocity stops are estimated from exertion/velocity profile (see Table 3 and Figure 5) and are highly correlated with how much exertion the athlete is experiencing and proximity to failure. Since the load/velocity profile and MVT are more stable than 1RM over time, this makes velocity stops a stable individual parameter, and provides key information in controlling the exertion levels and fatigue being generated. A practical example would involve performing multiple sets with 80% 1RM in the squat, keeping velocity above 0.45m/s, which is approximately 2 reps away from failure (see Table 3). This can be a useful tool for coaches and athletes over multiple sets and provides an easy way to auto-regulate training volume based on daily readiness of the athlete. The level of velocity stops will be subject to periodized training plans and will be based on the objective of the training session and planned workload for a given individual and exercise. In certain training sessions, where the objective might be to induce higher levels of fatigue, velocity stops will be very close to MVT (or no velocity stops will be used). In other cases where the coach wants to minimize the extent of fatigue, velocity stops will be set at high velocities, well above the exercise's MVT. This might be particularly useful in periods of peaking or tapering when athletes wish to maintain (or enhance) accrued strength gains as effectively as possible while minimizing the fatigue effects of training.

A similar approach has been examined in an intervention study to assess if high effort training and minimizing velocity loss during the set can significantly influence muscular strength. Padulo et al. (15) had a group of experienced strength trainers perform the bench press with a predetermined load of 85% 1RM. This training group performed an open-ended number of sets and reps with each set terminated when velocity dropped below a threshold of 20% velocity loss. The athletes ended the training session when they were unable to achieve the velocity threshold for that load for any reps within a set. Athletes in the control group completed 7-9 sets of 2-3 repetitions across the three-week intervention period. The training group significantly increased maximal strength (via 1RM testing) compared to baseline levels with very large effect sizes observed in comparison to a control group who trained with a more traditional "reps to failure" training approach. This study suggests that training with maximal effort and minimizing velocity loss can positively influence muscular strength.

These three research papers together (13, 15, 18) suggest that if appropriate velocity thresholds are implemented in resistance training that metabolic fatigue can be limited, maximal velocities can be maintained and maximal strength may be enhanced in short peaking training phases.

Practical Application 5 - Using velocity to prescribe exercise load.
Taking these recommendations further, instead of traditional exercise prescription of relative or absolute load and number of repetitions and sets (e.g. 100kg x 5 reps x 5 sets) one could prescribe loading using velocity bands and velocity stops (e.g. sets at 0.4 m/s initial velocity until rep velocity falls below 0.36m/s). This velocity-based approach has numerous advantages, such as being sensitive to day-to-day readiness fluctuations and changes in 1RM over longer training blocks. Velocity-based approaches also allows for auto-regulating and individualizing training volume and load using velocity bands and velocity stops for both reps (within-set) and sets (between sets using "average set velocity stops"). This also provides immediate real-time feedback which research suggests motivates athletes to apply consistent maximal lifting effort which has been associated with positive training effects (1, 16, 17). Further research on the benefits of velocity-based strength training compared to more traditional forms of strength training is warranted.

CONCLUSIONS

Mean concentric velocity measured via a LPT is a reliable and appropriate measure of movement velocity in basic strength training exercises such as the bench press and the squat. To establish a load/velocity profile for a specific exercise coaches should measure mean concentric velocity at 4-6 increasing intensities of load ranging from 30-85% of actual or estimated 1RM. Established load/velocity profile allows for more insightful comparison of the individuals, their monitoring over time and making informed training decisions.

Minimal velocity threshold (MVT) is the velocity associated with 1RM and last repetition of a set performed to failure regardless of the load being used. MVT is exercise specific and remains stable with changes in maximal strength (1RM) over time. Exertion/velocity profiles demonstrate that velocities at the same rep left in the tank are very similar (CV from 3 to 6%), regardless of the load being used (% of 1RM). The practical significance of this is that by monitoring repetition velocities during the set (assuming maximal effort) one can estimate the proximity of failure and exertion expressed by the athlete for a given set regardless of the load being used.

Knowing the MVT for a given individual and exercise allows for 1RM estimation using submaximal loads. This allows for monitoring day-to-day readiness or daily 1RMs and making training adjustments along with monitoring changes in maximal strength without imposing fatigue and interfering with normal training process. Easy monitoring of daily 1RMs allows for potential mathematical modelling of the training process and providing an individualized approach in load prescription and training block durations

Utilizing velocity stops in a given set allows the control of fatigue and exertion during strength training. Velocity monitoring also provides immediate real-time feedback which research suggests motivates athletes to apply consistent maximal lifting effort which has been associated with positive training effects. Using velocity bands to prescribe training load is a novel approach that is sensitive to day-to-day readiness fluctuations and changes in 1RM over longer training blocks. Together with velocity stops, utilizing velocity bands is a novel approach to strength training prescription that allows for auto-regulating and individualizing training volume and load.

REFERENCES

1. Behm, D.G. & Sale, D.G. Intended rather than actual movement velocity determines velocity-specific training response. **Journal of Applied Physiology**. 74: 359-368. 1993.
2. Bosco, C., Belli, A., Astrua, M., Tihanyi, J., Pozzo, R., Kellis, S., Tsarpela, O., Foti, C., Manno, R., Tranquilli, C. A dynamometer for evaluation of dynamic muscle work. **European Journal of Applied Physiology**. 70: 379: 386. 1995.
3. Bosquet, L., Porta-Benache, J., Blais, J. Validity of a commercial linear encoder to estimate bench press 1RM from the force-velocity relationship. **Journal of Sport Science and Medicine**. 9: 459-463. 2010.
4. Clarke D.C., Skiba P.F.. Rationale and resources for teaching the mathematical modeling of athletic training and performance. **Advances in Physiology Education**. 37: 134–152, 2013.
5. Cormie, P., McGuigan, M.R., Newton, R.U. Developing maximal neuromuscular power. Part 2 – Training considerations for improving maximal power production. **Sports Medicine**. 41: 125-146. 2011.
6. Crewther, B., Cronin, J. and Keogh, J. Possible stimuli for strength and power adaptation. Acute Mechanical Responses. **Sports Medicine**. 35: 967-989. 2005.
7. Cronin, J.B., Hing, R.D., McNair, P.J. Reliability and validity of a linear position transducer for measuring jump performance. **Journal of Strength and Conditioning Research**. 18:590 - 593. 2004.
8. Cronin, J.B., McNair, P.J. and Marshall, R.N. Force-velocity analysis of strength-training techniques and load: implications for training strategy and research. **Journal of Strength and Conditioning Research.** 17: 148-155. 2003.
9. González-Badillo, J.J., Marques, M.C., Sánchez-Medina, L. The importance of movement velocity as a measure to control resistance training intensity. **Journal of Human Kinetics Special Issue.** 15-19. 2011.
10. González-Badillo, J.J., Sánchez-Medina, L. Movement velocity as a measure of loading intensity in resistance training. **International Journal of Sports Medicine.** 31: 347 – 352. 2010
11. Hansen, K.T., Cronin, J.B., Newton, M.J. The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes. **Journal of Strength and Conditioning Research**. 25: 1447 - 1456. 2011.
12. Harris, N. K., Cronin, J., Taylor, K., Boris, J., Sheppard, J. Understanding position transducer technology for strength and conditioning practitioners. **Strength and Conditioning Journal**. 32: 66-79. 2010.
13. Izquierdo M., Gonzalez-Badillo J.J., Häkkinen K., Ibañez J., Kraemer W.J., Altadill A., Eslava J., Gorostiaga E.M. Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions. **International Journal of Sports Medicine.** 27: 718–724. 2006.
14. Jidovtseff, B., Harris, N.K.., Crielaard, J.M., Cronin, J.B. Using the load-velocity relationship for 1RM prediction. **Journal of Strength and Conditioning Research** . 25: 267-270. 2011.
15. Padulo, J., Mignogna, P., Mignardi, S., Tonni, F., Ottavio, S.D. Effect of different pushing speeds on bench press. **International Journal of Sports Medicine**. 33: 376-380. 2012.
16. Randell, A.D., Cronin, J.B., Keogh, J.W., Gill, N.D., Pedersen, M.C. 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: 87 – 93. 2011
17. Randell A.D., Cronin J.B., Keogh J.W., Gill N.D., Pedersen M.C. Reliability of performance velocity for jump squats under feedback and nonfeedback conditions. **Journal of Strength and Conditioning Research**. 25: 3514 - 3518. 2011
18. Sanchez-Medina, L., & González-Badillo, J.J. Velocity loss as an indicator of neuromuscular fatigue during resistance training. **Medicine and Science in Sports and Exercise**. 43: 1725–1734. 2011.
19. Sanchez-Medina, L., Perez, C.E., Gonzalez-Badillo, J.J. Importance of the propulsive phase in strength assessment. **International Journal of Sports Medicine.** 31: 123 – 129. 2010.
20. Vincent, W., Weir, J. **Statistics in Kinesiology – 4th Edition**. Champaign. IL: Human Kinetics. 2012.