USING VELOCITY IN THE WEIGHTROOM

BY DR. DAN BAKER

Introduction

Resistance training is an integral part of the total training that enhances sports performance. Traditionally, increases in strength have come about via two broad adaptations/mechanisms—muscle morphological adaptations and neural activation adaptations. Muscle morphological adaptations include increased muscle fiber size, change in fiber structure and architecture, change in muscle pennation angles providing a better line of pull, and possibly an increase in fiber number or satellite cell proliferation. Neural activation adaptations include increased activation of motor units within a muscle, increased rate of firing of motor units, and possibly some synchronization of firing of those motor units.

With these broad adaptations come the two main training methods to increase strength and power: moderate resistances and higher repetitions to improve muscle morphology, and very heavy weights and lower reps to improve neural activation.

This gives rise to two main training prescriptive methods. One is the repetition maximum (RM) method, whereby training may be prescribed as, for example, three sets of 8-10RM (3x8-10RM). The other is the percentage 1RM method, whereby training is prescribed at a designated percentage such 3x5 @ 80% 1RM. The effort or rating of perceived exertion (RPE) method, whereby the difficulty of the set is also considered, moderates these two methods. The effort/RPE method has several levels:

- Maximum effort (ME) is a set in which no additional repetitions can be performed (RPE = 10)
- Near-maximum effort (NME) is a set in which one more repetition could have been performed (RPE = 9)
- Hard effort (HE) is a set in which 2-3 more repetitions could have been performed (RPE = 8)
- Dynamic effort (ME) is a set in 4-6 more repetitions could have been performed (RPE = 7)
- And so on

Classic linear and block periodization programming are manifestations of these two methods. Early high-rep training weeks improve muscle size and morphology, while later weeks with heavier resistances and lower reps better activate the muscles. Effort manipulation varies the stress, irrespective of which block the athlete is in.

However, a different strength training concept has recently emerged. This concept was based upon measurements of velocity during training. Research in Spain revealed a few key findings:

- Those training with maximal velocity attained better strength and power results than those who do not train with maximal intended velocity (23);
- Velocity decreases fairly linearly across a set of traditional strength training exercises like bench presses and squats (27);
- Velocity is closely related to %1RM (22);

- Multiple sets at high effort levels and/or higher reps resulted in even more marked declines in velocity as well as higher lactate levels and greater ammonia (a muscle breakdown marker) levels (35).

Thus measuring and understanding changes in velocity during resistance training may aid in the training prescription. Velocity-based or influenced prescription emerged as an alternative programming paradigm (15, 21-23, 28, 29).

Measuring velocity during resistance training is not new, but previously it was restricted to elite athletes and typically only done on explosive power exercises such as jump squats and ballistic bench presses because of the expense and lack of portability (29, 34). Plenty of data already existed to illustrate that higher velocity or power levels with absolute loads clearly distinguish between higher and lower ranked athletes (3, 5, 13) and that athletes make improvements in power/velocity measures over time (4-7, 10, 26). However, the evidence showed the velocity attained with any standard absolute load was affected by training status and recovery levels as well (4, 21, 22). Thus the idea began germinating that monitoring velocity levels on a more regular basis could provide greater insights into daily strength levels, fatigue levels, and “readiness/peaking” (20, 21, 29, 30).

Coaches and athletes must understand a number of things before embarking upon velocity-based or influenced training. Once these things are understood, the applied examples detailed later in this paper become more evident.

Six important theoretical things to know!

1. Differences in average versus peak velocity

The PUSH armband has two key velocity/power measures, average and peak. Average velocity measures velocity across the entire concentric lifting portion of the rep. Peak velocity is the highest velocity in any 5-msec portion of that rep.

Average velocity is highly related to any given %1RM for an individual in key “strength training” exercises and the best single velocity measure to monitor for those exercises (21, 22). Peak velocity is more closely related to performance in “power training” exercises (19, 20, 38) and is now thought to be the best single velocity measure to monitor for those exercises. However, there is also a tremendous amount of data and research using average velocity for “power exercises” (2-13). It is very easy to monitor both with the PUSH armband.

2. Strength versus power exercises—average versus peak velocity

What distinguishes the two broad categories of “strength training” and “power training” exercises is whether the exercise entails a marked deceleration period toward the end of the range of movement when lifting lighter resistances (eg <60%1RM) or acceleration through the full range of motion and resultant higher velocities (1). For example, lighter squats and bench presses with resistances below 50%1RM result in a large portion of the concentric portion of the rep being associated with deceleration (36); therefore, the body has to reduce the velocity and force of the rep as a self-protection mechanism to guard against jerking the tendons and damaging the joint as it comes to an abrupt stop at end of range (32, 39). Alternatively, jump squats and bench press throws (in a Smith machine) allow full acceleration and higher velocities as the energy of the rapid muscle contraction is released into the air, rather than abruptly stopping (32, 39). Most jumping, throwing, kicking and almost all Olympic weightlifting exercises can be defined as “power” exercises as they entail the two key ingredients—higher movement velocities and acceleration through the full range of movement (1, 8, 9).

Traditional “strength” exercises (squat, bench press, deadlifts, pull-ups, etc.) are best trained with medium resistances and higher reps for muscle morphology adaptations or heavier resistances and lower reps for neural activation adaptations (even though there is very little deceleration during heavy resistance strength training, the slower velocities do not make them, by themselves, ideal for power development) (1). Traditional strength exercises become more like power exercises by altering them to include a large portion of the total resistance through bands and chains (e.g. 45% 1RM + 20%1RM in band/chain resistance) so there are higher movement velocities and acceleration through the full range of movement (9, 14).

Regardless of the exercise category, measuring and monitoring velocity appears to be an exciting way to gauge progress, daily strength/power levels, “readiness/peaking” status for training or competition (21, 22, 29, 30).

3. Some relevant average & peak velocity data

Table 1 depicts some key velocity measures garnered from research for resistances over 60% 1RM for the major strength exercises. There is actually a paucity of data for most exercises, with the bench press being the most studied. Also, because of differences in measurement techniques or methods, there are also some discrepancies in the data, so I have deliberately omitted some of it. Furthermore, much squat and bench press research has been performed in a Smith machine with athletes whose strength levels could most accurately be described as “moderate.” More research is needed on free weight exercises among athletes with varied strength levels to determine if very strong athletes differ from moderately strong and less strong ones, for example.

Nonetheless, existing data shows that as resistances increase towards 100% 1RM, velocity decreases. Also Tables 1-4 clearly show there is not some universal velocity zone across all exercises, meaning each exercise has a different velocity-load profile. Bench press, bench pull, and—from empirical experience—most upper-body strength exercises exhibit a fairly linear relationship between increasing loads and decreasing velocities. Squat exercises tend to exhibit a linear relationship only to about 80%1RM, when the decrement in velocity with increasing loads is less linear and quite subtle.

Thus the velocity-load profile for squats is much different for bench press and bench pulls. So while some coaches postulate that 0.7–1.0 m/s is the zone to train for strength-speed, this would result in very different %1RM training zones for bench press (50-60+% 1RM), bench pulls (65-85% 1RM), and squats (0-40%1RM) (17, 21, 22, 37).

Exercise	60% 1RM	70% 1RM	80% 1RM	90% 1RM	100% 1RM
Bench press (37)	0.77 (0.07)	0.61 (0.06)	0.46 (0.05)	0.31 (0.05)	0.17 (0.04)
Bench press (21)	0.80 (0.05)	0.64 (0.05)	0.48 (0.04)	0.33 (0.04)	0.19 (0.04)
Bench pull (37)	1.06 (0.09)	0.92 (0.09)	0.79 (0.08)	0.65 (0.07)	0.52 (0.06)
Squat (17)	0.56	0.47	0.37	0.32	< 0.3
Deadlift (18)	0.50		0.30 85%=		
Exercise	**55% 1RM**	**65% 1RM**	**75% 1RM**		
Bench press (21)	0.87 (0.05)	0.71 (0.05)	0.55 (0.04)		
Bench press (14)	0.87 (0.07)	0.72 (0.08)	0.57 (0.07)		

Table 1. Some average velocity data for key strength exercises.

Exercise	50% 1RM	60% 1RM	70% 1RM	80% 1RM	90% 1RM	100% 1RM
Squat (39)	0.80 (0.10)	0.72 0.09	0.62 (0.10)	0.58 (0.14)	0.54 (0.10)	NA
Bench press (28)	1.47 (0.08)		1.01 (0.09)		0.59 (0.12)	

Table 2. Some peak velocity data for key strength exercises.

Peak velocity	BWT	10% BWT	20% BWT	30% BWT	40% BWT	50% BWT
International rugby 7's players (31)	3.9 (0.3)					
Female team sport athletes (38)	3.0	2.7	2.6	2.4	2.3	2.1
Male team sport athletes (38)	3.1	2.9	2.75	2.65	2.45	2.35
			25% BWT	**50% BWT**	**75% BWT**	**100% BWT**
Male national swimmers (68.2 kg) (19)			2.4 (0.09)	2.09 (0.06)	1.83 (0.05)	1.62 (0.05)
Female national swimmers (57.6 kg) (19)			2.02 (0.03)	1.78 (0.03)	1.52 (0.03)	1.34 (0.03)

Table 3. Some peak velocity data for jump squats.

College athletes (24)	Power clean @80%1RM 2.0	
Elite lifters (25)	Snatch 1.68–1.98	Snatch 1st pull 1.13–1.26
Chinese elite female (16)	Clean 1.57	Clean 1st pull 0.96
Male elite (20)	Clean 1.59	Clean 1st pull 0.87

Table 4. Some peak velocity data for Olympic-style weightlifting exercises

4. How to determine strength levels from velocity data

There appear to be numerous ways of assessing strength levels from average velocity data, apart from the estimation used in PUSH tests.

Method 1. For the best rep (often the first), comparing that velocity against the tables above gives an idea of %1RM of any given training load. Comparing average velocity from the best rep within a set to the normal scores in the tables above is quite simple. For example, if an athlete's best average velocity bench pressing 80 kg is 0.47 m/s, this would equate to 80% 1RM; therefore, their 1RM bench press would be about 100 kg. This is fairly simple if velocity/%1RM charts are on gym walls or in a phone/tablet. However, this method is predicated upon the athlete lifting with maximal intended velocity, which does not always happen and is in the "normal distribution."

While this method is fairly reliable, individuals vary. If the 1RM bench press average velocity is 0.17 m/s with a standard deviation (SD) of .04 to 0.05 m/s, 67% of the populations will attain their 1RM with a velocity of 0.13 to 0.21 m/s. However, most elite athletes are not "normal," but exceptional, especially some power athletes. They may be as much as 2 or even 3x SD from normal scores!

The author has measured former Olympic track athletes whose 1RM and last rep of a 5RM bench press velocity were both 0.25 m/s, more than 2x SD from "normal" velocity associated with a maximum effort bench press repetition. Therefore, this method is more accurate when data is obtained from individuals over time, rather than just comparing with established normal scores. Figure 1 below is an example of three elite rugby players performing explosive bench press sets. Therefore, their scores are more than twice the SD above what is normal at 63% 1RM.

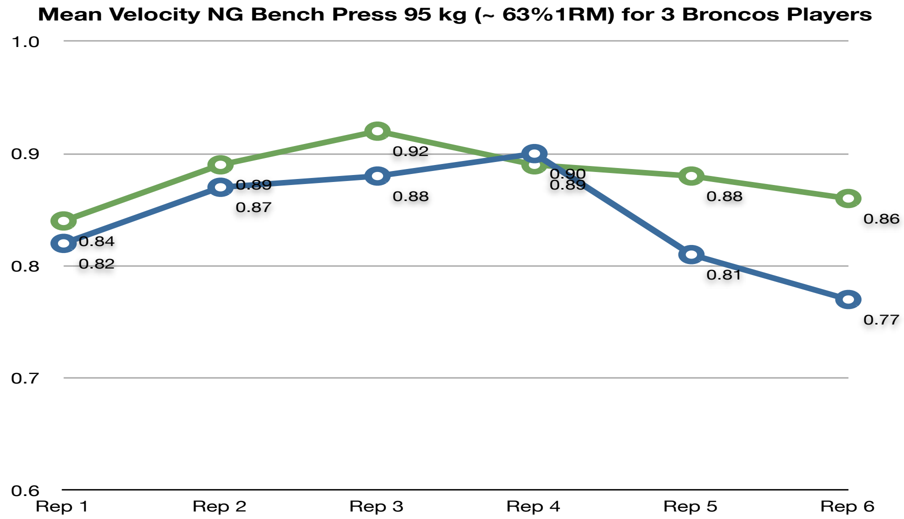

Figure 1. The average velocity attained during two sets of six reps of the bench press for three "explosive" power athletes. Their scores of >0.92 m/s are more than twice the normal SD for a resistance of 63%1RM (~0.74 m/s).

Method 2. During a set performed to fatigue, the last rep will have the same velocity as that person's 1RM. So if a lifter has a 1RM bench press average velocity of 0.18 m/s, their third rep of a 3RM, fifth rep of a 5RM, and eighth rep of an 8RM will all be at (or very close to) that 0.18 m/s velocity. Therefore, the velocity of best rep not only tells us about strength levels but also provides the velocity of the worst rep within a set, the number of reps performed, and insight into strength and effort levels.

Not all sets are performed to fatigue. If a bench press set is stopped one rep short of fatigue, the velocity of the last rep will equate to a 2RM (about 0.25 m/s, 95% 1RM). If stopped two reps short, last rep velocity will equate to a 3RM (about 0.33 m/s 92% 1RM). For three short, the velocity of the last rep will equate to a 4RM (about 0.38 m/s, 88% 1RM)—and so on. For squats, a set performed to fatigue will have a final rep velocity of below 0.3 m/s (see Figure 2 below). If a set is stopped one rep short of fatigue, the velocity will equate to a 2RM (about 0.33 m/s, 95% 1RM), if stopped two reps short, the velocity will equate to a 3RM (about 0.36 m/s 92% 1RM), and so on. But note that the relationship between squat %1RM and velocities is not as linear as compared to a bench press at intensities above 80%1RM.

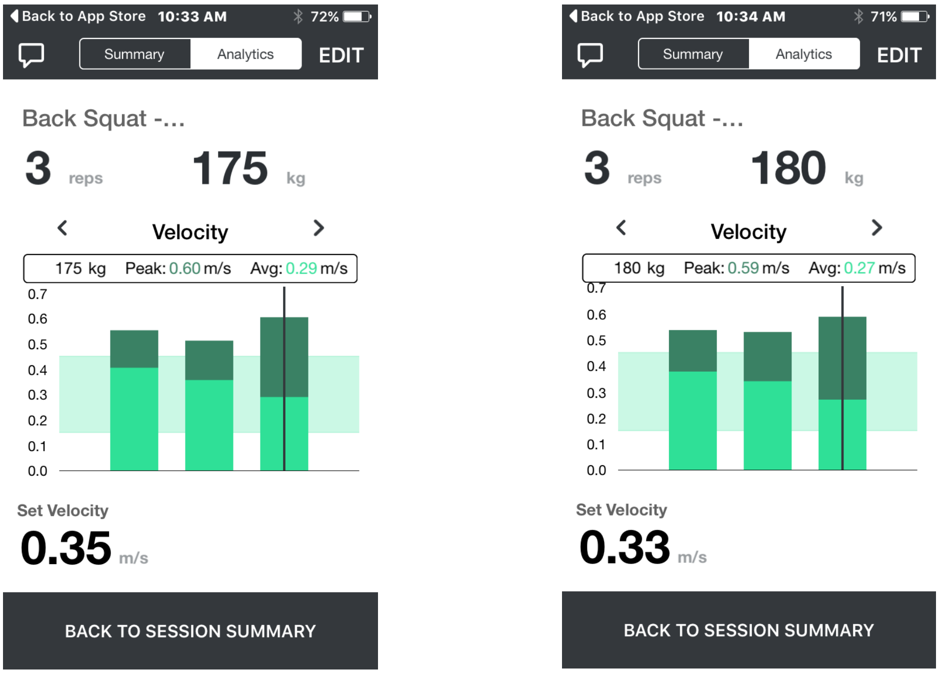

Figure 2. In these squat examples, the athlete has lifted to 3RM level two weeks in a row. The average velocity of the last rep is 0.29 m/s and 0.27 m/s, respectively. Any squat rep below 0.3 m/s tends to signify maximum effort. This athlete's velocities for the second rep of his 2RM (185 kg) and his 1RM (190 kg) are both 0.25 m/s.

Method 3. The correlation between velocity at a %1RM and 1RM is very high in the bench press ~ r =0.98 (21). As the velocity decrements in bench press (and bench pull) are fairly linear across loads, changes in velocity of the order of 0.07 m/s equate to changes in strength levels of 5% 1RM. So if an athlete's bench press velocity with a set of absolute load increases from 0.40 m/s to 0.47 during a few weeks/months, it means their 1RM has increased by about 5%.

Or this formula can be used for bench press to determine %1RM of any given absolute load, based upon average velocity (AV) of the best reps (21):

$$\textbf{Load as \%1RM} = 7.5786\ AV^2 - 75.865\ AV + 113.02$$

For example, if the average velocity = 0.45 m/s

$$(7.5786*0.45^{2)} - (75.865*0.45) + 113.02$$

$$= 1.5436 - 34.139$$

$$= -32.5954 + 113.02$$

$$= 80.42\%1RM$$

While this formula method of tracking progress appears to hold true for bench press, a comparable formula does not hold true for free weight barbell squats as yet because the increase in load and decrement in velocity are not linear above 80%. However, a formula has been developed for concentric-only (from the pins) half-squats (15). Consequently, the best method for tracking progress above 80%1RM in squats and deadlifts is a simple comparison to previously performed training data (Methods 1 and 2).

5. Relationships between velocity, strength exercises, and fatigue

There are also distinct relationships not only between strength and velocity but also velocity and physiological markers of fatigue/muscle damage like lactate and ammonia levels. Generally, the higher the repetitions and the closer to fatigue (or maximum effort) during the performance of three sets, the greater the velocity decline and the higher the physiological markers of fatigue/muscle damage (35). This is more pronounced for upper body than lower body training (35).

Coaches can therefore choose the level of these fatigue/damage markers they want their athletes to experience. The key thing to remember is: ***Large decreases in velocity and large increases in lactate and ammonia make it more difficult to recover from the resistance training session.***

If hypertrophy is the goal of training in a preparation period, higher rep prescriptions to full fatigue level (e.g. 3x10RM or 12RM) may be appropriate, knowing that this fatiguing session may negatively impact performance in other training sessions like running or sports skills. However, reducing the reps slightly and not going to fatigue results in a marked reduction in fatigue/damage markers (e.g. 3x8 @10RM), so this may also be considered an option if marked interference with other training is not acceptable. For in-season hypertrophy maintenance, the prescription of 3x6 @ 10RM may be more manageable with regards to fatigue/damage induced in resistance training sessions interfering with other training sessions.

For strength and power training, the lower-rep, not-to-fatigue options (e.g. 3x3 @ 6RM or 3x2 @ 4RM) appear to offer a better option of minimal fatigue/damage markers while still lifting over 80%1RM with reasonable velocities.

	SQ velocity % decline	BP velocity % decline	SQ Lactate mmol	BP Lactate mmol	SQ Ammonia	BP Ammonia
3 x 12RM	46.5	63.3	12.5	8.9	125	111
3 x 10RM	45.7	58.4	11.7	7.8	97	89
3 x 8RM	39.8	56.9	10.4	7.5	78	79
3 x 6RM	41.9	56.8	10.0	6.9	65	68
3 x 4RM	32.0	49.8	6.9	4.9	61	53
3x8 (10RM)	32.3	46.1	8.6	6.0	62	64
3x6 (10RM)	22.0	29.8	6.3	4.6	48	47
3x3 (6RM)	19.6	23.7	3.5	3.1	47	51
3x2 (4RM)	16.6	18.8	3.0	2.6	41	48

Table 5. Adapted from reference 35.

6. Relationships between velocity, power exercises, and fatigue

Power training exercises have a key peak velocity parameter, otherwise the lift is typically not successful. This means the clean is not racked, the jerk does not lock out, the jump squat does not attain the desired height, and so forth, if a certain peak velocity is not attained. Accordingly, there cannot be as a large a decline in velocity across a number of sets for power exercises as compared to the strength exercises in Table 5.

Below are two examples of velocity decline for Olympic weightlifting derivative exercises. In the power clean example, the last rep of the set is about 1.79 m/s compared to 2.0 m/s, a decline of 10% across six reps (24). If we refer back to Table 4, we see elite lifters who clean at 1.59 m/s – power cleans are typically faster, so a score of around 1.6 to 1.7 m/s may be the minimum peak velocity that allows the clean to be successfully racked. So if perhaps eight or more reps are performed at 80%1RM, there may be a velocity decline well below 1.7 m/s, thereby indicating the lift is unsuccessful.

	Rep #1	**Rep #6**	**% decline**
Set 1	2.00 (0.05)	1.79 (0.03)	10.5%
Set 2	1.98 (0.04)	1.80 (0.03)	9.1%
Set 3	1.95 (0.05)	1.79 (0.03)	8.9%

Table 6. Power clean "peak" velocity decline – 3x6 reps with 80%, 3 minutes rest between sets (reference 24).

Mean velocity	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**Average**
Set 1	0.99	0.94	0.95	0.94	1.00	0.98	0.96	0.96	**0.97**
Set 2	0.95	0.99	0.96	1.01	1.00	1.03	0.85	0.98	**0.97**
Set 3	0.92	1.06	0.98	0.99	0.97	1.13	1.06	1.04	**1.02**
Set 4	1.04	0.98	1.00	0.98	0.90	1.02	0.91	0.99	**0.98**

Table 7. The average velocity for each rep of four sets of eight reps @ 70% 1RM with snatch push press. Because the lifter has not performed reps to fatigue, there is no decline in velocity within each set or across the sets. The peak velocity data (not displayed) was typically above 1.8 m/s. If the average and peak dropped below 0.85 and 1.7 m/s for this athlete, the lift tended to be unsuccessful.

REFERENCES

1. Baker D**.** “Selecting the appropriate exercises and loads for speed-strength development.” *Strength & Conditioning Coach* 3(2):8-16. 1995.

2. Baker, D. “A series of studies on the training of high intensity muscle power in rugby league football players.” *J. Strength Cond. Res*., 15(2):198-209. 2001.

3. Baker, D. Comparison of maximum upper body strength and power between professional and college-aged rugby league football players. *J. Strength Cond. Res*. 15(1):30-35. 2001.

4. Baker, D. “Acute and long-term power responses to power training: Observations on the training of an elite power athlete.” *Strength and Condit. J.* 23(1):47-56. 2001.

5. Baker, D. “The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league players.” *J. Strength Cond. Res*. 15(2): 172-177. 2001.

6. Baker, D. “Six- year changes in upper-body maximum strength and power in experienced strength-power athletes.” *Journal of Australian Strength & Conditioning*. 16(3):4-10. 2008.

7. Baker, D. “Ten-year changes in upper body strength and power in elite professional rugby league players—the effect of training age, stage and content.” *J. Strength Cond. Res*. 27(2): 285–292. 2013.

8. Baker, D. “Combining scientific research into practical methods to increase the effectiveness of maximal power training.” *Journal of Australian Strength & Conditioning*. 24(1):4-17. 2016.

9. Baker, D. and Newton, R. U. “Methods to increase the effectiveness of maximal power training for the upper body.” *Strength and Conditioning Journal*. 27(6):24-32. 2006.

10. Baker, D. and Newton, R. U. “Adaptations in upper body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes.” *J. Strength Cond. Res*. 20(3):541-546. 2006.

11. Baker, D. and Newton, R. U. “Analyses of tests of upper body strength, power, speed and strength-endurance to describe and compare playing rank in professional rugby league players.” *International Journal of Sports Physiology and Performance*, 1(4): December. 2006.

12. Baker, D and Newton, R.U. “Observation of 4-year adaptations in lower body maximal strength and power output in professional rugby league players.” *Journal of Australian Strength & Conditioning*. 16(1): 3-10. 2008.

13. Baker, D. & Newton, R. “Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players.” *J. Strength Cond. Res*. 22(1):153-158. 2008.

14. Baker, D and R. U. Newton. “Effect of kinetically altering a repetition via the use of chain resistance.” *J. Strength Cond. Res*. 23(7):1941-1946. 2009.

15. Bazuelo-Ruiz, B, Padial, P, Garcıa-Ramos, A, Morales-Artacho, AJ, Miranda, MT, and Feriche, B. "Predicting maximal dynamic strength from the load-velocity relationship in squat exercise." *J. Strength Cond Res*. 29(7): 1999–2005. 2015.

16. Deming, L., Kangwei, A., and W. Yunde. "Three dimensional analysis of the clean and jerk techniques for female elite Chinese weightlifters." National Research Institute of Sports Science, Beijing, P.R. China.

17. Farris, D., Lichtwark G., Brown N., and A. Cresswell. "Deconstructing the power resistance relationship for squats: A joint-level analysis." *Scand J Med Sci Sports*. 1-8. 2015.

18. Galpin, A., Malyszek, K., Davis, K., Record, S., Brown, L., Coburn, J., Harmon, R, Steele, J., and A. Manolovitz. "Acute effects of elastic bands on kinetic characteristics during the deadlift at moderate and heavy loads." *J Strength Cond Res*. 29(12):3271–3278. 2015.

19. García-Ramos, A, Stirn, A, Padial, P, Argüelles-Cienfuegos, J, De la Fuente, B, Strojnik, V, and B Feriche. "Predicting vertical jump height from bar velocity." *J. Sports Science & Medicine*. (14):256-262. 2015.

20. Garhammer, J. "A comparison of maximal power outputs between male and female weightlifters in competition." *Int. J. Sport Biomech*. (7)3-11. 1991.

21. González-Badillo JJ, Sánchez-Medina L. "Movement velocity as a measure of loading intensity in resistance training." *Int J Sports Med*. 31:347–352. 2010.

22. González-Badillo JJ, Marques MC, Sánchez-Medina L. "The importance of movement velocity as a measure to control resistance training intensity." *J Hum Kinet*. Special Issue:15–19. 2011.

23. González-Badillo J, Rodríguez-Rosell D, Sánchez-Medina L, Gorostiaga E, Pareja-Blanco F. "Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training." *Eur J Sport Sci.* 14(8):772-81. 2014.

24. Hardee, JP, Triplett, NT, Utter, AC, Zwetsloot, KA, and McBride, JM. "Effect of inter-repetition rest on power output in the power clean." *J Strength Cond Res*. 26(4):883–889. 2012.

25. Ho, LKW, Lorenzen, C, Wilson, CJ, Saunders, JE, and Williams, MD. "Reviewing current knowledge in snatch performance and technique: The need for future directions in applied research." *J Strength Cond Res*. 28(2):574–586. 2014.

26. Izquierdo M, Häkkinen K, González-Badillo JJ, Ibáñez J, Gorostiaga EM. "Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports." *Eur J Appl Physiol*. 87: 264–271. 2002.

27. Izquierdo, M, González-Badillo, J, Hakkinen, K, Ibanez, J, Kraemer, W, Altadill, A, Eslava, J. and Gorostiaga, E. "Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions." *Int J Sports Med*. 27: 718–724. 2006.

28. Jandacka, D. and D. Zahradnik. "The validity of velocity measurement during upper-body resistance exercises under variable loads." International Symposium on Biomechanics in

SportsConference. 28:1-4. 2010.

29. Jidovtseff, B, Harris, NK, Crielaard, JM, and Cronin, JB. "Using the load-velocity relationship for 1RM prediction." *J Strength Cond Res*. 25: 267–270, 2011.

30. Jovanović, M. and E. Flanagan. "Researched applications of velocity based strength training." *Journal of Australian Strength & Conditioning*. 22(2)58-69. 2014.

31. Mitchell, J., Pumpa, K., Williams, K.,and D. Pyne. "Variable changes in body composition, strength and lower body power during an international rugby sevens season." *J Strength Cond Res*. (published ahead of print). 2015.

32. Newton, R, Kraemer, W, Hakkinen, K, Humphries, B, and Murphy, A. "Kinematics, kinetics and muscle activation during explosive upper body movements." *J Appl Biomech*.12: 31–43. 1996.

33. Ramos-Veliz, R, Suarez-Arrones, L, Requena, B, Haff, GG, Feito, J, and Sáez de Villarreal, E. "Effects of in-competitive season power-oriented and heavy resistance lower-body training on performance of elite female water polo players." *J Strength Cond Res*. 29(2): 458–465. 2015

34. Ramírez J, Núñez V, Lancho C, Poblador M. and J Lancho. "Velocity-based training of lower limb to improve absolute and relative power outputs in concentric phase of half-squat in soccer players." *J Strength Cond Res*. 29(11):3084-8. 2015.

35. Sanchez-Medina, L and Gonzalez-Badillo, JJ. "Velocity loss as an indicator of neuromuscular fatigue during resistance training." *Med Sci Sports Exerc*. 43:1725–1734. 2011.

36. Sanchez-Medina, L, Perez, CE, and Gonzalez-Badillo, JJ. "Importance of the propulsive phase in strength assessment." *Int J Sports Med*. 31:123–129. 2010.

37. Sanchez-Medina, L, Gonzalez-Badillo, J., Perez, C., and J. Pallares. "Velocity- and power-load relationships of the bench pull vs. bench press exercises." *Int J Sports Med*. 35. 209–216. 2014.

38. Taylor, S. and K. Taylor. "Normative data for mechanical variables during loaded and unloaded countermovement jumps." *Journal of Australian Strength & Conditioning*. 22(2):20-27. 2014.

39. Wilson GJ, Newton RU, Murphy AJ, and Humphries BJ. "The optimal training load for the development of dynamic athletic performance." *Med Sci Sports Exerc*. 25:1279–1286. 1993

40. Zink, AJ, Perry, AC, Robertson, BL, Roach, KE, and Signorile, JF. "Peak power, ground reaction forces, and velocity during the squat exercise performed at different loads." *J Strength Cond Res*. 20:658– 664. 2006.