

Velocity-Based Training for Monitoring Training Load and Assessing Training Effects



Fernando Pareja-Blanco  and Irineu Loturco

Abstract Currently, velocity-based training (VBT) is one of the hot topics in sport science and among strength and conditioning coaches. However, its wide use has spread some misunderstandings of the fundamental concepts of this methodology. It should be highlighted that this is not a new training method, but rather, a new approach that enables more accurate, frequent, and objective control of resistance training intensity and volume. The VBT approach is no other thing than recording lifting velocity every repetition during resistance training. The quantification of actual repetition velocities achieved during resistance training sessions provides a more consistent and precise understanding of training effects, opening up the possibility to establish causal relationships between stimuli and response, which is one of the main and most important targets of research and practice in sport science. As such, VBT can be defined as a resistance training method that uses movement velocity to improve training process and enhance training effects, via a deeper understanding of the input signal (actual training load) and the output signal (changes in performance). Through this chapter we will see how VBT contributes to improve the resistance training methodology, as well as discuss its potential benefits, limitations, and practical implications.

Keywords Strength training • Movement velocity • Velocity loss • Training prescription • Dose-response

F. Pareja-Blanco (✉)

Physical Performance and Sports Research Center, Pablo de Olavide University, Seville, Spain

e-mail: fparbla@upo.es

I. Loturco

NAR—Nucleus of High Performance in Sport, São Paulo, Brazil

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

A. Muñoz-López et al. (eds.), *Resistance Training Methods*, Lecture Notes in Bioengineering, https://doi.org/10.1007/978-3-030-81989-7_9

153

1 Introduction

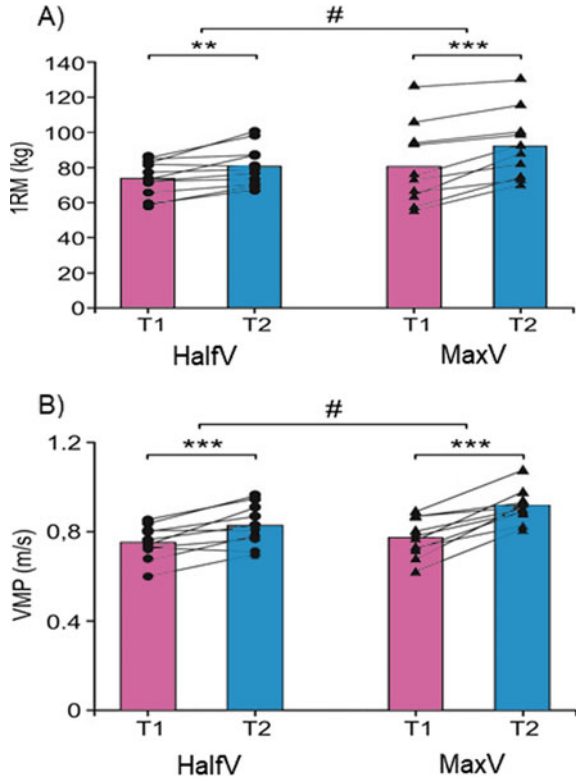
Velocity-based training (VBT) is one of the hot topics in scientific literature and among strength and conditioning coaches. However, its wide use has spread some misunderstandings of the fundamental concepts of this methodology. It should be highlighted that it is not a new training method, but a novel approach that allows accurate and objective control of resistance training (RT) intensity and volume as well as of training effects. Put simply, VBT consists of measuring and recording every repetition during RT. The quantification of repetition velocities during RT provides a more precise understanding of the resistance exercise stimuli and their possible effects (i.e., training adaptations). This fact opens up the possibility to establish causal relationships between stimulus and response, which is certainly one of the main targets of research in sport science. Specifically, VBT can be defined as an RT approach that uses movement velocity to optimize training process by means of a deeper information about the “input signal” (actual training load) and the “output signal” (actual changes in performance). Through this chapter, it addresses how VBT contributes to improve the RT methodology and provide some practical applications and examples of its use.

2 From Theory

2.1 *Lifting at Maximal Velocity is the Essential Premise of Velocity-Based Training*

As described in the Introduction section, VBT can be used whenever the repetition velocity is recorded. The essential premise of VBT is that the concentric phase of each repetition should always be performed at maximal voluntary velocity. This should be interpreted as an important aspect of VBT rather than a shortcoming, since the velocity at which the loads are lifted determines the training intensity and, consequently, the training effects. In this context, RT intensity is more than solely the magnitude of the load (%1RM) being lifted, as the velocity at which loads are actually moved affects the acute and chronic training responses (Pareja-Blanco et al. 2014; Gonzalez-Badillo et al. 2014). With regard to the influences of movement velocity on training intensity, the greater the velocity against a given load, the higher the applied force (Schilling et al. 2008). As a result, the greater the velocity against a given load, the lower the difference between the force value achieved with this “relative load” and the force applied against the maximum load that can be lifted in a specific exercise (i.e., lower strength deficit) (Loturco et al. 2021a). Concerning training effect, it has been shown that performing squat repetitions at maximal concentric velocity compared to “intentionally slower velocity” (i.e., half-velocity) led to greater gains in squat performance (one-repetition maximum “1RM” strength as well as the velocity developed against any load, from light to heavy) and vertical jump height (Fig. 1a) (Pareja-Blanco et al. 2014). Similar

Fig. 1 Effect of the maximal voluntary velocity (MaxV) compared to half-maximal velocity (HalfV) bench-press training on: **a** one-repetition maximum (1RM) and **b** average velocity attained against absolute loads common to pre-(T1) and post-(T2) test in the bench-press progressive loading test. Significant group \times time interactions: # $P < 0.05$. Intra-group significant differences from pre- to post-training: ** $P < 0.01$, *** $P < 0.001$. Adapted from Gonzalez-Badillo et al. (2014)



findings were observed for the bench-press exercise (Fig. 1b) (Gonzalez-Badillo et al. 2014). Moreover, when the load is lift at maximal intended velocity, this results in higher recruitment of motor units and level of neural activation (Desmedt and Godaux 1977; Behm and Sale 1993), despite spending shorter time under tension (Schilling et al. 2008). Therefore, for maximizing training adaptations when using VBT, it is necessary to lift the loads at the maximal intended velocity.

2.2 Using Movement Velocity to Determine Loading Intensity

A common concern of strength and conditioning coaches is how to objectively and precisely quantify and monitor the actual training load undertaken by trainees. Among the main RT variables (Suchomel et al. 2018; Kraemer and Ratamess 2004), exercise intensity is certainly one of the most critical, since this determines the direction and extent of the resulting adaptations (Bird et al. 2005; Fry 2004). The most common reference to prescribe RT intensity is the 1RM value (i.e., the maximum load that can be lifted successfully once in a given exercise) (Kraemer and Ratamess 2004; Buckner et al. 2017). Accordingly, RT intensity is expressed as percentages of 1RM (%1RM) (Scott et al. 2016). Likewise, exercise intensity may

be prescribed by using an indirect measurement: the maximal number of repetitions that can be performed when using submaximal loads (MNR, e. g., 5RM, 10RM, 15RM). This method is based on the relationship already observed between the % 1RM and the MNR, which established a “RM continuum” (Brzycki 1993; Reynolds et al. 2006), allowing coaches to estimate the 1RM through the use of a derived equation. Despite their extensive utilization, these methods present important shortcomings, such as: (1) very time-consuming and laborious procedures (Loturco et al. 2016; Rontu et al. 2010); (2) high risk of injury when performed incorrectly (Chapman et al. 1998; Braith et al. 1993); (3) they can induce high levels of muscle damage, potentially hampering physical and technical performance on the following days (Niewiadomski et al. 2008). Furthermore, it is known that the MNR that can be performed with a given relative load differs between athletes (Richens and Cleather 2014; Sánchez-Moreno et al. 2021a) and, thus, a given MNR load may represent different %1RM for different subjects, leading to erroneous estimation of training intensity. In addition, the 1RM value can either fluctuate on a daily basis or change throughout the training program, which may produce that the prescribed load may not match the intended %1RM. Consequently, there is a need to implement faster, safer, and more practical methods to estimate both maximum (i.e. 1RM) and relative (i.e. %1RM) RT loads. The possibility of using a more precise and consistent “non-exhaustive approach” to determine the 1RM would allow coaches to frequently correct and adjust training loads even during habitual training sessions. In this sense, a pioneering study reported a very strong relationship ($R^2 = 0.98$) between %1RM and lifting velocity in the BP exercise (Fig. 2) (Gonzalez-Badillo and Sánchez-Medina 2010). Subsequently, several investigations confirmed that lifting velocity is a valid measure to objectively and frequently quantify training intensity in different exercises. From these data, multiple predictive equations have been developed, allowing practitioners to estimate loading magnitude (%1RM) under different training settings. This close relationship enables practitioners to rapidly and accurately determine the individual’s current 1RM values and what percentages of 1RM are being used as soon as the first repetition of the set is performed with maximal voluntary velocity, without exposing trainees to the exhaustive and time-consuming traditional 1RM or MNR measurements (Gonzalez-Badillo and Sánchez-Medina 2010; Gonzalez-Badillo et al. 2011).

Given these relevant findings, it is not surprising the increased interest in applying the load-velocity relationship as a tool to define and monitor RT intensity. However, prescribing RT intensity using barbell velocity as a reference has a drawback: movement velocity is exercise-dependent and, consequently, a given velocity may represent different intensities for distinct exercises. Thus, in order to properly use the movement velocity as a tool to prescribe and estimate absolute and relative loads for a given exercise, the load-velocity relationship should be properly established for this exercise. As a consequence, the load-velocity relationship has been analyzed in a myriad of exercises, such as: full-squat (Sánchez-Medina et al. 2017) and different squat-variants (Loturco et al. 2016; Conceicao et al. 2016; Martinez-Cava et al. 2019), leg-press (Conceicao et al. 2016), deadlift (Benavides-Ubric et al. 2020), hip-thrust (Hoyo et al. 2019), bench-press (Gonzalez-Badillo and

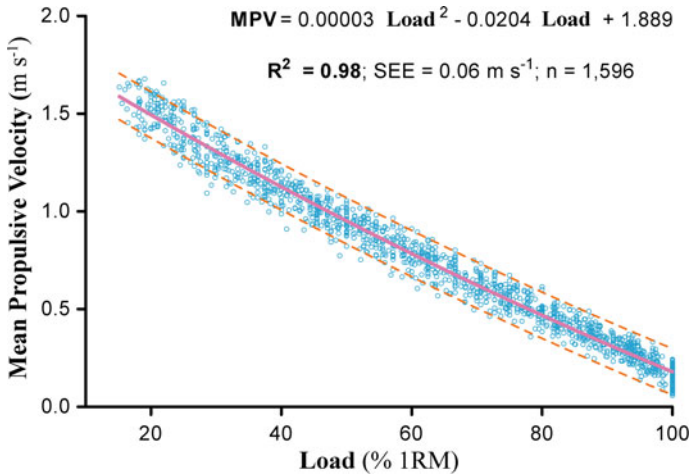


Fig. 2 Relationship between relative load (%1RM) and mean propulsive velocity in the bench-press exercise. Solid line shows the fitted curve to the data, and the dotted lines indicate the 95% confidence limits of the estimation. Adapted from Sánchez-Medina (2010)

Sánchez-Medina 2010), bench-pull (Sánchez-Medina et al. 2014), military-press (Balsalobre-Fernández et al. 2018), pull-up (Sánchez-Moreno et al. 2017), prone row (Loturco et al. 2021b), among others. Coaches and practitioners should regularly use these findings on a daily basis, adjusting the absolute load (kg) to match the repetition velocity associated with the %1RM that is intended for the RT session (Table 1).

Table 1 Mean propulsive velocity (m·s⁻¹) attained against each percent 1RM in different resistance exercises

Load (%1RM)	Bench-press	Bench-pull	Pull-up	Full-squat	Deadlift
40	1.11	1.35		1.13	1.09
45	1.02	1.28		1.07	1.02
50	0.94	1.20		1.00	0.96
55	0.85	1.13		0.93	0.90
60	0.77	1.06		0.87	0.83
65	0.69	0.99	0.83	0.80	0.77
70	0.61	0.92	0.74	0.73	0.71
75	0.53	0.85	0.66	0.67	0.64
80	0.46	0.79	0.57	0.60	0.58
85	0.38	0.72	0.48	0.53	0.52
90	0.31	0.65	0.39	0.46	0.45
95	0.24	0.59	0.30	0.40	0.39
100	0.17	0.52	0.20	0.33	0.33

Values based on Sánchez-Medina et al. (2014); Sánchez-Moreno et al. (2017); Pareja-Blanco et al. (2020d); Benavides-Ubric et al. (2020)

2.3 *Using Movement Velocity as a Measure of Level of Effort Within the Set*

Another important training variable that should be considered when designing RT programs is the training volume (Spiering et al. 2008; Schoenfeld et al. 2017). Regarding the related-training volume parameters, the level of effort—defined as the actual number of repetitions performed within the set in relation to the maximum number of repetitions (MNR) that can be completed (Sánchez-Medina and Gonzalez-Badillo 2011)—has been claimed as a critical factor in determining adaptations to strength training (Pareja-Blanco et al. 2020a, 2017a). Accordingly, the degree of fatigue and, consequently, the training adaptations, will be substantially different when performing, for example, four out of eight repetitions with a given load [4(8)] compared to completing all possible repetitions [8(8)]. In this regard, the level of effort has traditionally been determined by fixing beforehand a specific number of repetitions to complete in each exercise set when using a sub-maximal load (i.e., %1RM) (Sánchez-Medina and Gonzalez-Badillo 2011; Pareja-Blanco et al. 2020b). However, the MNR that can be completed with a given %1RM shows large inter-individual variability (coefficient of variation [CV]: 8.6–33.1%) (Sánchez-Moreno et al. 2021a; Gonzalez-Badillo et al. 2017). This fact may lead to different levels of effort among athletes performing the same number of repetitions per set even when using a similar %1RM, because the number of repetitions that remain undone (i.e., repetitions left in reserve) may considerably differ between them (Moran-Navarro et al. 2019; Rodriguez-Rosell et al. 2020a). These considerations suggest that it is necessary to find better ways to objectively monitor the actual level of effort experienced by athletes during RT sets. Accordingly, rather than completing a fixed and predetermined number of repetitions in each set, each training set should be stopped as soon as a certain level of performance impairment is detected, which will depend on the specific target being pursued (Pareja-Blanco et al. 2020a, 2017a, 2020c). When performing each repetition at maximal voluntary effort during a training set, the force applied and, hence, movement velocity and power output will progressively decline, as a consequence of the development of fatigue (Fig. 3) (Ortega-Becerra et al. 2021; Izquierdo et al. 2006). In this regard, the velocity loss (VL) incurred within the set, which is calculated as the relative difference between the fastest (usually the first) and the last repetition performed, has been proposed as an objective, practical, and non-invasive indicator of neuromuscular fatigue during RT (Sánchez-Medina and Gonzalez-Badillo 2011). Indeed, high relationships ($R^2 = 0.83–0.94$) have been observed between the repetition VL and different mechanical and metabolic measures of fatigue (Sánchez-Medina and Gonzalez-Badillo 2011). Likewise, it has been observed strong relationships ($R^2 = 0.92–0.97$) between the VL incurred within the set and the percentage of repetitions completed with regard to MNR (%Rep, i.e. proximity to muscle failure) for relative loads ranging between 50–85% 1RM in the bench-press and full-squat exercises (Sánchez-Moreno et al. 2021a; Gonzalez-Badillo et al. 2017; Rodriguez-Rosell et al. 2020a). Moreover, the %Rep completed to a given magnitude of VL

presented a low inter-individual variability (CV: 2.5–12.1%) and a high reliability (intra-individual CV: 2.1–6.6%) (Gonzalez-Badillo et al. 2017). Therefore, the %Rep for a given magnitude of VL is very similar for all individuals, regardless the MNR that could be completed. These findings allow practitioners to estimate with a high precision the %Rep that has already been performed and/or as a result how many repetitions are left in reserve, as soon as a given VL magnitude is attained in the exercise set. However, the pattern of repetition velocity decline seems to be exercise-specific (Rodriguez-Rosell et al. 2020a). According to previous research, when athletes have completed approximately 50% of the MNR, the VL magnitude is about 20–25% in the bench-press, full-squat, and pull-up exercises (Rodriguez-Rosell et al. 2020a). Figure 5 depicts the %Rep corresponding for different magnitudes of VL in bench-press, full-squat, and pull-up exercises. Thus, instead of previously defining a fixed number of repetitions to perform against a given load, practitioners may use different VL thresholds to obtain more accurate information about the actual degree of fatigue incurred during the set as well as to prescribe more effective and tailored training sessions (Table 2).

2.4 Effort Index as a New Method to Quantify Training Load During Resistance Training

As it has been described in the two previous epigraphs, the close relationship between bar velocity and relative intensity in different exercises, and between the magnitude of VL within the set and the percentage of performed repetitions (%Rep) against a given load confirm that VBT is a valid and accurate approach for

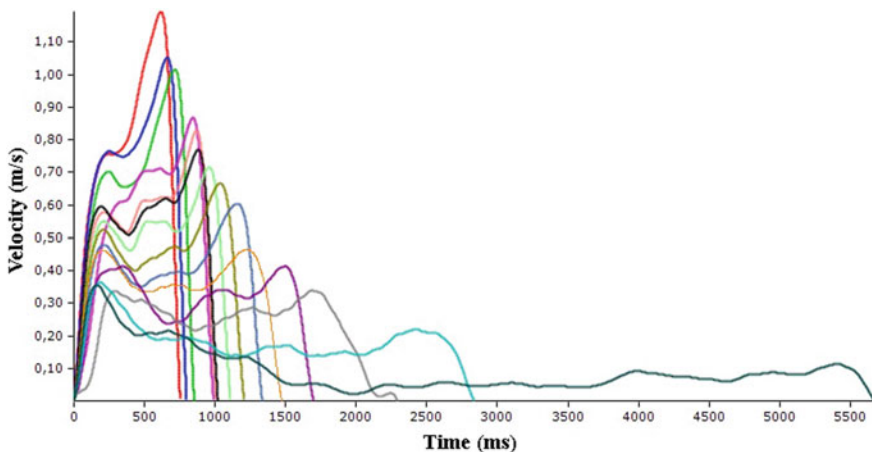


Fig. 3 Evolution of lifting velocity throughout a set in the bench-press exercise conducted up to the task failure

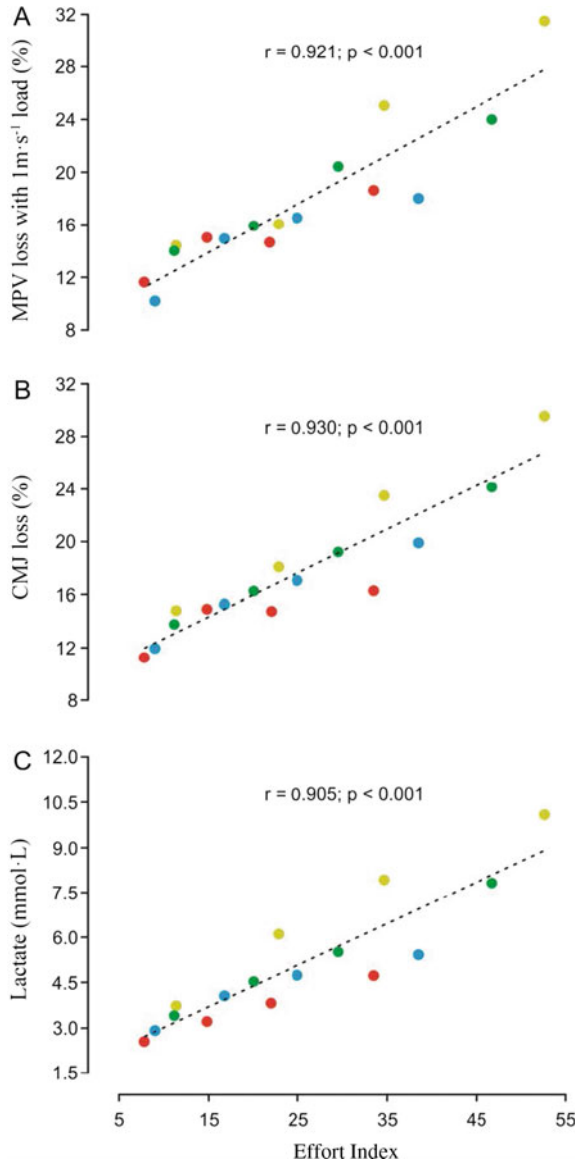
Table 2 Percentage of completed repetitions out of the maximum possible number when a given magnitude of mean propulsive velocity loss is reached in each set to failure in the bench press, full-squat and pull-up exercises

Velocity loss (%)	Percentage of completed repetitions out of the maximum possible number when a given velocity loss is reached (%)		
	Bench-press	Full-squat	Pull-up
10	20–25	25–30	25–30
15	30–35	35–40	30–35
20	35–40	45–50	40–45
25	45–50	55–60	50–55
30	50–55	60–65	55–60
35	55–60	65–70	65–70
40	65–70	75–80	70–75
45	70–75	80–85	75–80
50	75–80	85–90	80–85
55	80–85	90–95	85–90
60	85–90	90–100	90–95
65	95–100	95–100	95–100

Values based on González-Badillo et al. (2017); Sánchez-Moreno et al. (2017); Rodríguez-Rosell et al. (2020a)

monitoring RT intensity and volume. Therefore, instead of prescribing a certain amount of weight to be lifted and a given number of repetitions per set, training prescription may be based on the first repetition's velocity and the magnitude of VL over the set. This also opens up the possibility of quantifying the fatigue induced during RT by the interaction of these two parameters. In this regard, the product of the first repetition's mean velocity and the magnitude of VL induced within the set, termed as the "effort index", was shown to be strongly associated with certain fatigue indicators, such as the VL against a given absolute load and post-exercise blood lactate concentrations (Fig. 4) (Rodríguez-Rosell et al. 2018). Moreover, the effort index showed moderate to strong relationships with jump height loss and with relative changes in some surface electromyography (EMG) variables, such as the instantaneous median and mean frequency of the EMG power spectrum (Rodríguez-Rosell et al. 2020b). Previous studies have already reported that the higher the VL with a specific load, the higher the muscle fatigue induced by the training set (Sánchez-Medina and Gonzalez-Badillo 2011; Weakley et al. 2019a). Nonetheless, the effort index allows the comparison of fatigue incurred during the training session even when different relative loads are employed. When comparing similar VL thresholds between loads of different magnitudes, it is possible to observe that lower relative loads will produce higher degrees of fatigue (Rodríguez-Rosell et al. 2018). This may be explained by the fact that the number of repetitions performed to achieve a given percentage of VL in the set is lower as the %1RM increases. Likewise, the lower number of repetitions required to attain a given VL with heavier loads may be explained by the fact that the higher the load, the higher the degree of effort of each repetition. In practical terms, this indicates

Fig. 4 Relationships between effort index and loss of velocity pre-post exercise against the $V1 \cdot m \cdot s^{-1}$ load, jump height loss and post-exercise lactate concentration for the squat exercise. Each data point corresponds to one different resistance exercise protocol. Different colors are used to differentiate between the different relative intensities analyzed: 50% 1RM (yellow), 60% 1RM (green), 70% 1RM (blue), and 80% 1RM (red). Adapted from Rodríguez-Rosell (2017)



that heavier loads will result in greater magnitudes of VL for a similar number of repetitions (Sánchez-Medina and Gonzalez-Badillo 2011; Rodríguez-Rosell et al. 2020a). The strong correlations observed between effort index and different fatigue indicators suggest that, for a given effort index, the degree of fatigue experienced is equivalent, regardless of the first repetition's velocity and the magnitude of VL incurred in the set. However, it should be highlighted that, although similar degrees

of fatigue are experienced by trainees, the mechanisms underlying fatigue likely differ between training stimulus with similar effort index but with different %1RM and VL magnitudes.

3 From Practice

3.1 How the Use of Movement Velocity as a Measure of Training Intensity Can Be Easily Implemented on a Daily Basis

As explained in the epigraph 2.2, the very close relationship between relative load and bar velocity results in mean velocity values strongly associated with distinct % 1RM. Therefore, intensity can be prescribed on a daily basis, using a very precise and time-saving approach, by adjusting the absolute load (kg) to match the repetition velocity associated with the respective percentage of 1RM intended for a given training session. However, it should be acknowledged that individual factors such as age, sex, or training status may potentially influence the prediction equation.

3.1.1 Individual Load-Velocity Relationship

The 1RM and %1RM estimations calculated from the velocity attained with distinct submaximal loads are usually based on general load-velocity equations. These equations assume that the velocity associated with each relative load is the same for all individuals; however, some inter-individual aspects, such as execution technique, length of members, fiber type composition, among others, may slightly compromise these estimations. Accordingly, the individual load-velocity relationship has been proposed to overcome these limitations. In this regard, it has been shown that individual load-velocity relationships provide more accurate predictions of %1RM than general equations (Benavides-Ubric et al. 2020; Pestana-Melero et al. 2018; Garcia-Ramos et al. 2018). Indeed, González-Badillo and Sánchez-Medina (2010) in their seminal work already reported almost perfect individual load-velocity relationships for a sample comprising 120 healthy men aged 24.3 ± 5.2 years, with a training experience of 1.5–4 years ($R^2 = 0.996 \pm 0.003$; range: 0.983–0.999; CV = 0.3%). The standard test carried out to determine the individual load-velocity relationship entails of recording lifting velocity with several submaximal loads and, afterward, modeling the load-velocity relationship through a linear or polynomial (depends on the exercise) adjustment to estimate the 1RM as the load corresponding to the velocity at which the 1RM is attained.

In an attempt to find the potential mechanisms underlying the small differences in the load-velocity relationship among individuals, the influence of different

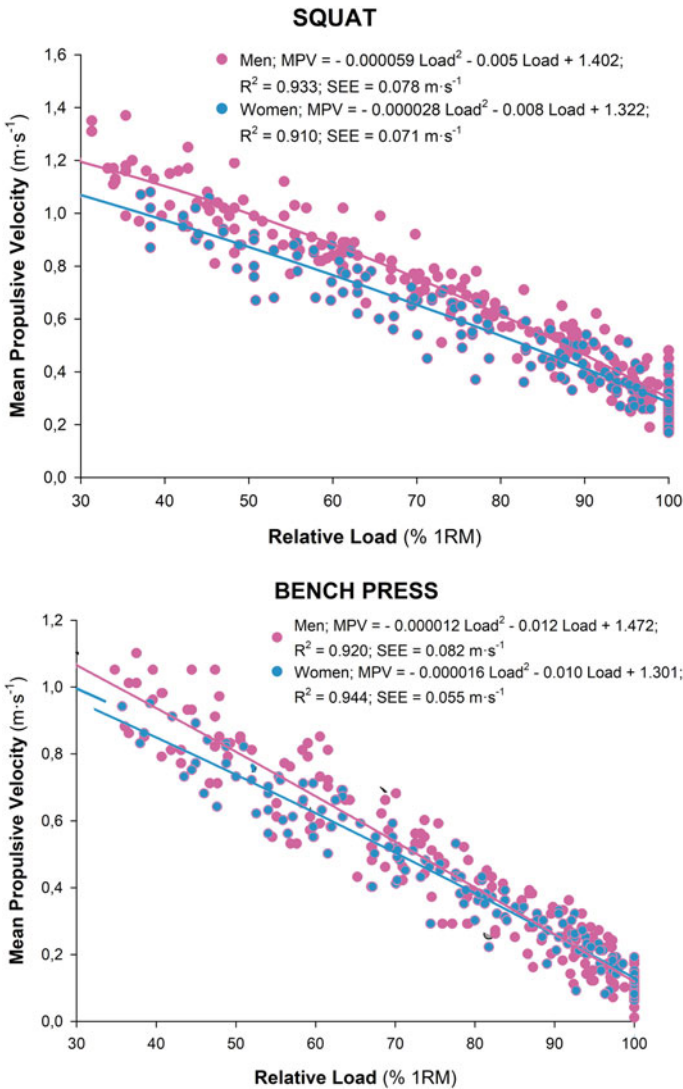


Fig. 5 Relationships between relative load and bar velocity for the full-squat and bench-press exercises. Data obtained from raw load-velocity values derived from the progressive loading tests performed on the sample of 25 men and 13 women. Black circles represent men and grey circles represent women. MPV: mean propulsive velocity. SEE: standard error of estimate. Adapted from Pareja-Blanco et al. (2020d)

strength levels and changes in performance have been investigated. In this regard, the load-velocity relationship seems similar for age-matched individuals with different strength levels (Loturco et al. 2016,2017; Gonzalez-Badillo and Sánchez-Medina 2010; Torrejón et al. 2019) and for the same individuals with

increased strength levels after a RT program (Gonzalez-Badillo and Sánchez-Medina 2010; Sánchez-Moreno et al. 2017). Notwithstanding, it has been observed that the velocity associated with each %1RM, particularly with light and moderate loads, is higher in men compared to women in both upper- and lower-body exercises (Fig. 5) (Balsalobre-Fernández et al. 2018; Torrejón et al. 2019; Pareja-Blanco et al. 2020d; García-Ramos et al. 2019). Nevertheless, the velocity of the 1RM did not differ between sexes (Balsalobre-Fernández et al. 2018; Pareja-Blanco et al. 2020d; García-Ramos et al. 2019). Therefore, the general equations previously published for some exercises (Loturco et al. 2016,2017; Gonzalez-Badillo and Sánchez-Medina 2010; Sánchez-Medina et al. 2017) may not be suitable for women. Accordingly, if the training load is prescribed with the same velocity value for both men and women, the training stimulus for both sexes may be different. As a consequence, although the lifting velocity is a valid tool to estimate the relative load in both sexes, a more precise prediction can be obtained when a sex-specific equation is used. The fact that women attain similar %1RM at slower velocities than men may indicate that women have higher strength deficit than men, which should be understood as the percentage of maximal strength potential which is not used (or applied) during a given motor task (Loturco et al. 2021a). However, the underlying mechanisms of differences in the load–velocity relationship between sexes require further investigation. Similarly, young men attain higher velocities for every %1RM than middle-aged men (Fernandes et al. 2018). These findings highlight the need to individualize the load-velocity relationship to the trained population.

3.1.2 Using Bar Velocity on a Daily Basis

The VBT approach allows coaches and athletes to monitor performance by measuring the velocity of the barbell (or load) which is being moved during a lift. In this regard, an increase in the bar velocity may indicate an increase in maximum strength, while an immediate decrease in bar velocity may suggest an impaired ability to apply force (possible due to fatigue). As a result, the velocity against a submaximal absolute load (kg) can be regularly monitored during the warm-up of key RT exercises, thus providing objective and accurate information about the changes in the athlete's fitness/fatigue status. Moreover, by monitoring repetition velocity, it is possible to determine in real-time whether the proposed load (kg) actually represents the effort (%1RM) that was intended in the training session. This allows making adjustments to the training load accounting for day-to-day fluctuations, resulting in more tailored and effective training programs (Dorrell et al. 2020).

The use of feedback during RT is a powerful tool for promoting both acute and chronic improvements in certain physical capacities (Nagata et al. 2020; Weakley et al. 2019b). VBT provides feedback in real-time, which can enhance motivation and, hence, the performance attained in each repetition. In this regard, Nagata et al. (2020) reported that providing verbal feedback of bar velocity after each loaded

jump squat repetition resulted in acute and long-term improvements in physical performance. Therefore, this approach may serve as a motivational tool not only to increase training accuracy and quality, but also, to optimize gains in physical performance.

3.2 Effects of Different Velocity Loss Thresholds During Resistance Training

As previously mentioned, the level of effort, which is defined as the relationship between the actual number of repetitions performed in the set with regard to the MNR that can be completed (Sánchez-Medina and Gonzalez-Badillo 2011), should be prescribed by the VL attained within the RT set, in order to prevent the drawbacks of determining beforehand a number of repetitions to be performed with a given load (Gonzalez-Badillo et al. 2017). Long-term adaptations to RT seem to be dependent on the VL incurred within the training set during a training program. In this regard, high VL thresholds ($\geq 40\%$), which accumulate high levels of RT volume by performing more fatiguing and slower repetitions, maximize muscle hypertrophy (Pareja-Blanco et al. 2017a, 2020a, c), but these VL thresholds can also induce negative neuromuscular adaptations (Pareja-Blanco et al. 2020a). These high hypertrophic responses may be due to the high exercise-induced metabolic and mechanical stress, elevated growth-promoting hormones responses, and high levels of muscle damage (Schoenfeld 2010; Goldberg et al. 1975), which are typically observed in RT protocols with higher VL thresholds (Sánchez-Medina and Gonzalez-Badillo 2011; Pareja-Blanco et al. 2020b; Moran-Navarro et al. 2017). In contrast, moderate VL thresholds (i.e. 10–20%) evoke positive neuromuscular adaptations, as well as increases in maximal neuromuscular excitation and enhancements in muscle stiffness indicators (Pareja-Blanco et al. 2020c; Rodriguez-Rosell et al. 2020c). Likewise moderate VL thresholds (10–25%) seem to maximize strength gains (Pareja-Blanco et al. 2017a, 2020a, c; Rodriguez-Rosell et al. 2020c). Indeed, higher VL thresholds do not induce further 1RM strength gains than lower VL thresholds and could even result in lower strength gains, especially in high-velocity actions against low-loads or unloaded conditions or when short periods of time are available to apply force (i.e. early rate of force development) (Pareja-Blanco et al. 2020b, c). This phenomenon may be related to a reduction in the IIX fiber type pool, which present faster cross-bridge cycling rates (compared to type I fibers) (Bottinelli et al. 1996) subsequent to an RT program using a 40% VL, while a 20% VL preserved this pool (Pareja-Blanco et al. 2017a). Accordingly, the dose–response relationship between the level of effort within the set, quantified by the VL, and performance adaptations has been suggested to exhibit an inverted U-shaped curve (Fig. 6) (Pareja-Blanco et al. 2020a, c; Rodriguez-Rosell et al. 2020c). This relationship indicates that a progressive increase in the level of effort within the set will be accompanied by an increase in strength gains, up to a certain limit, beyond which an increase will not produce additional benefits in terms of

muscle strength, which may be even detrimental for strength gains. In this regard, moderate VL thresholds (10–25%) should be used to maximize athletic performance, since low VL thresholds (<10%) seem to induce very low levels of fatigue to maximize adaptations, while high VL thresholds ($\geq 40\%$) do not produce further strength gains (Pareja-Blanco et al. 2020a,c). Hence, the training efficiency is higher for moderate VL thresholds compared to higher VL magnitudes, since moderate VL thresholds evoke similar or even greater benefits. Furthermore, higher VL thresholds (40%) result in greater fatigue and slower rate of recovery than lower VL thresholds (20%) (Pareja-Blanco et al. 2019). Accordingly, moderate VL thresholds induce similar or even greater strength gains than higher VL magnitudes with the advantage of requiring shorter recovery times. In summary, a minimal VL threshold is necessary and effective to optimize strength gains. However, performing additional repetitions under higher magnitudes of VL does not seem to elicit additional strength gains and may even induce “suboptimal adaptations”.

3.3 How the Use of Movement Velocity as a Measure of Level of Effort Can Be Practically Implemented on a Daily Basis

It has been shown that both velocity and power could be better preserved during the set by using the VL threshold as a training approach (Weakley et al. 2019a). In addition, the number of repetitions required for attaining a given magnitude of fatigue within the sets may be reduced throughout the training session, which can be individualized when using the VL approach (Weakley et al. 2019a). Accordingly, prescribing level of effort incurred within the set using VL thresholds may enhance exercise quality by mitigating neuromuscular fatigue as well as enables strength and conditioning professionals taking into account factors associated with individual differences in strength performance, daily readiness, or within-session fatigue development. Monitoring of repetition velocity is currently possible by means of the ever increasing number of commercially available portable measuring systems (linear position and velocity transducers, accelerometers, mobile apps, and inertial measurement units). This approach is of great practical relevance for practitioners aiming to find optimal and more time-efficient RT stimuli. In a previous study, a professional soccer team was divided into two groups that trained the squat exercise with similar relative loads but under distinct VL thresholds: one group trained under a VL of 15% (VL15) and the other under a VL equal to 30% (VL30) (Pareja-Blanco et al. 2017b). The VL15 group obtained similar or even greater gains than VL30 in all tested physical qualities (i.e., jump, sprint, and muscle strength) despite the fact that they performed a considerably lower number of repetitions (60% of the repetitions completed by the VL30 group) (Pareja-Blanco et al. 2017b). Likewise, another study compared the effects of two VL thresholds (10% vs. 20%) during a matched-intensity and matched-volume jump squat training

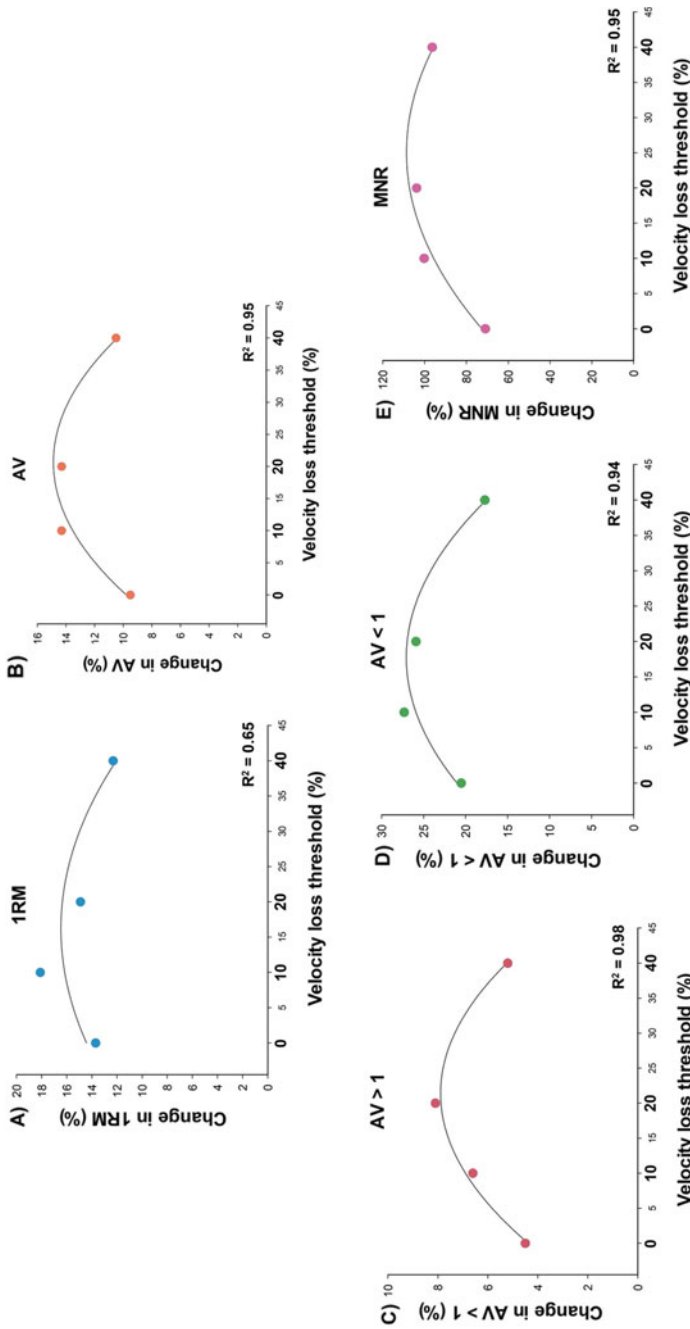


Fig. 6 Relationship between velocity loss in the set in the squat and change obtained in 1RM (a), average velocity attained against absolute loads common to pre and post in the progressive loading test (AV; b), average velocity attained against absolute loads common to pre and post that were moved faster than $1 \text{ m}\cdot\text{s}^{-1}$ ($AV > 1$; c), average velocity attained against absolute loads common to Pre and Post that were moved slower than $1 \text{ m}\cdot\text{s}^{-1}$ ($AV < 1$; d), and maximal number of repetitions to failure (MNR; E) after the resistance training programs from 70 to 85% 1RM in the full squat exercise. Adapted from Pareja-Blanco et al. (2020a)

program on athletic performance (Perez-Castilla et al. 2018). Both VL thresholds (10% and 20%) resulted in similar performance gains (i.e., jump height, maximal power output and maximal velocity); however, no changes were observed for maximal strength and sprint capacities (Perez-Castilla et al. 2018). Importantly, moderate VL thresholds (10–20%) in the squat exercise induce greater enhancements in high-speed actions, such as jumping and sprinting, than higher VL thresholds (30–40%) (Pareja-Blanco et al. 2017a,b; Rodriguez-Rosell et al. 2020c), which is of great importance for athletes aiming to maximize their performance without generating an excessive degree of fatigue during RT which could interfere, for example, on some technical and tactical skills. Moreover, since the change in lifting velocity against a given load is directly dependent on the force applied onto this load, an increase in the lifting velocity may be considered as an indicator of strength improvement (Loturco et al. 2021c). From a practical standpoint, this means that this approach may allow for the measurement of the estimated 1RM in every training session. Thus, based on the current evidence in this regard, it is possible to state that moderate VL magnitudes induce faster and greater strength gains than higher VL thresholds (Fig. 7), which is very relevant for sports requiring the maintenance of high levels of strength throughout the season.

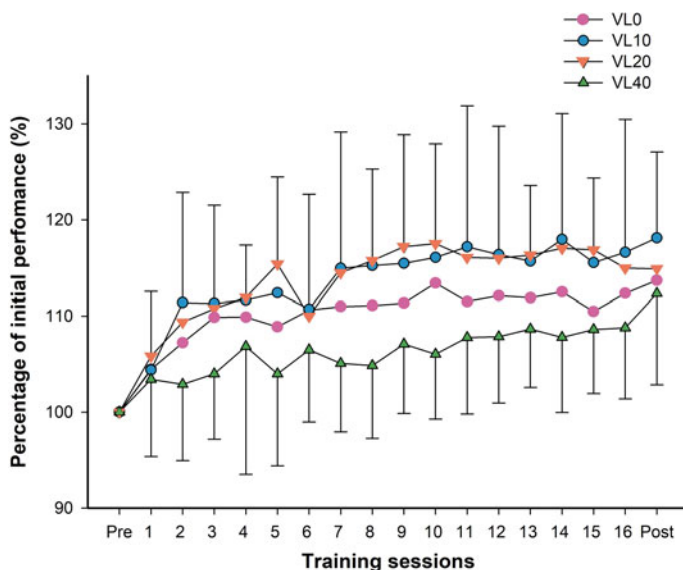


Fig. 7 Evolution of the 1RM strength in the squat exercise in each training session expressed as a percentage of the initial pre-training level for each experimental group. 0, 10, 20, or 40 indicate the session from which the respective group attained significant improvements ($P < 0.05$) in 1RM strength compared with their pretraining values. Data are mean \pm SD, $N = 55$. VL0: group that trained with a mean VL of 0% in each set ($n = 14$); VL10: group that trained with a mean VL of 10% in each set ($n = 14$); VL20: group that trained with a mean VL of 20% in each set ($n = 13$); VL40: group that trained with a mean VL of 40% in each set ($n = 14$). Adapted from Pareja-Blanco et al. (2020a)

4 Filling Gaps

4.1 Programming Using Velocity-Based Training

Programming is considered the manipulation of RT variables (i.e. exercise choice and order, relative intensity, volume, ratio between work and rest time, among others) with the intention of maximizing athletic performance (Cunanan et al. 2018). There are different programming models concerning the evolution of relative loads and volume throughout the training program as: linear programming (LP), in which training intensity gradually increases while volume decreases (Haff and Triplett 2015); undulating programming (UP), in which both volume and intensity increase or decrease repeatedly throughout the training program (Rhea et al. 2002); reverse programming (RP), in which training intensity gradually decreases and volume increases (Rhea et al. 2003); and constant programming (CP), in which both intensity and volume remain constant throughout the training program (Fig. 8a) (Schiotz et al. 1998). Although a myriad of works have already tried to analyze the effects of different programming models on strength gains (Williams et al. 2017; Harries et al. 2015; Loturco et al. 2013), previous research comparing different programming models have determined RT intensity based on the percentage-based training method, which, as previously described, cannot ensure that the actual load corresponds to the scheduled one, due to day-to-day fluctuations in performance. Since the VBT approach can account for these fluctuations by monitoring velocity during the warm-up and throughout training sessions, it is possible to determine and adjust the RT intensity and level of effort with high accuracy, in real time and on a daily basis. In this regard, a pioneering study compared the effects of four programming models (LP vs. UP vs. RP vs. CP) using VBT approach to prescribe both training intensity (50–85% 1RM) and level of effort (20% VL) (Riscart-Lopez et al. 2021). After 8 training weeks, the four programming models resulted in similar improvements in squat performance (i.e., 1RM strength and load-velocity spectrum), and jumping and sprinting capacities (Riscart-Lopez et al. 2021). However, the time-course of improvements in squat strength varied between groups, being less pronounced in the UP (Fig. 8b) (Riscart-Lopez et al. 2021). Another recent investigation also compared the effects of two different VBT programming models on physical performance. Both VBT programs (“LP” and “UP”) used similar relative intensities (ranging from 50 to 80% 1RM) and level of effort (15% VL) (Rodriguez-Rosell et al. 2021). The LP model resulted in greater strength gains than UP (Rodriguez-Rosell et al. 2021). Moreover, the enhancements in jumping ability and 1RM strength were earlier and uninterrupted for LP in comparison with DP (Rodriguez-Rosell et al. 2021). This finding is of great practical relevance when selecting RT models according to time-related criteria (i.e., prioritizing or not prioritizing faster and greater adaptations in strength-related capacities). As such, the use of the VBT approach to determine RT intensity and level of effort allows for an accurate, flexible, and tailored prescription of different programming models, which certainly increases training efficiency and performance gains.

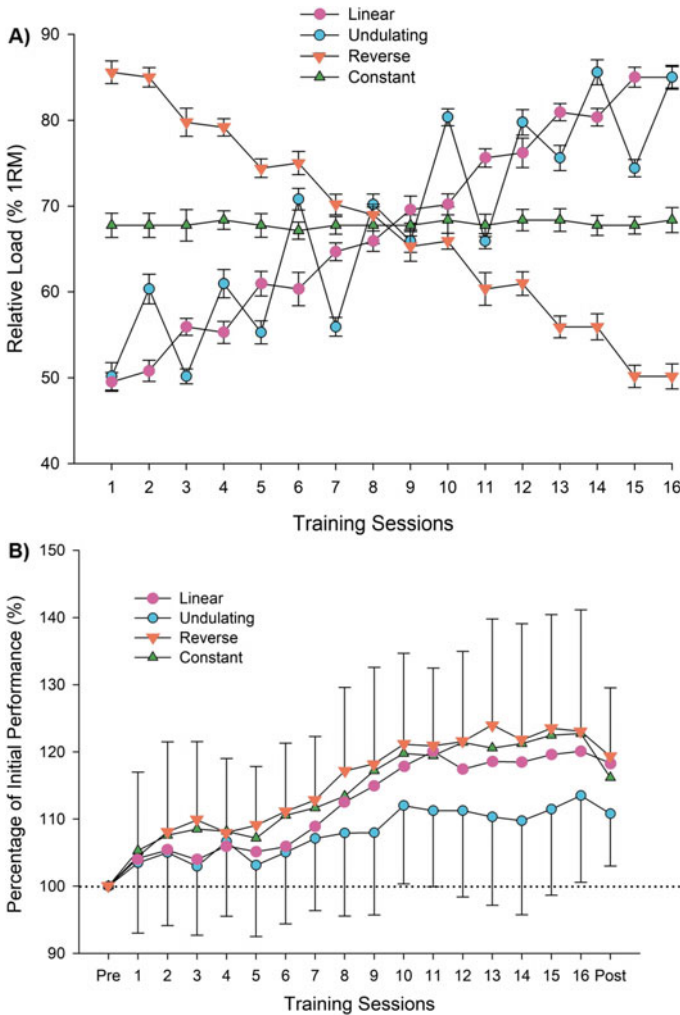


Fig. 8 a Example of using different programming models via the velocity-based training approach. **b** Evolution of 1RM across training sessions with respect to baseline performance for each experimental group. Data are presented as mean \pm SD. LP = linear programming (n = 11); UP = undulating programming (n = 10); RP = reverse programming (n = 11); CP = constant programming (n = 11). Adapted from Riscart-Lopez et al. (2020)

4.2 How to Design Concurrent Training Implementing the Velocity-Based Training Approach

Concurrent training consists of combining endurance and strength training (Hickson 1980). This training modality is regularly used in sports disciplines requiring high levels of strength and endurance (Garcia-Pallares and Izquierdo

2011). Due to time constraints or/and sport demands, elite athletes are frequently required to conduct both strength and endurance trainings within short periods of time. The exercise sequence (i.e., strength prior to endurance training or vice versa) and the extent of fatigue induced by each exercise may be critical for maximizing endurance and strength development (Doma et al. 2019), since the residual fatigue generated by the previous exercise may compromise the quality in the following exercise (Eddens et al. 2018). In this regard, a recent study compared the acute effects of training sequence and level of effort during RT when using four different training protocols, as follows: endurance training (ET) (running 10 min at 90% of maximal aerobic velocity) followed by RT (3 squat sets with 60% 1RM) with 20% and 40% VL, respectively [1) ET + RT20 and 2) ET + RT40]; and RT with 20% and 40% VL, respectively, followed by ET [3) RT20 + ET and 4) RT40 + ET] (Najera-Ferrer et al. 2021). In summary, higher VL magnitude (40% VL) during RT resulted in higher metabolic and mechanical stress (i.e. greater blood lactate and higher impairments in jump and strength capacities), and greater performance decrements in endurance-related variables (i.e., impaired running time and increased ventilatory equivalents) (Table 3) (Najera-Ferrer et al. 2021). However, endurance performance was not affected when RT with a moderate VL was performed before ET (i.e. RT20 + ET) (Najera-Ferrer et al. 2021). These findings suggest that high-fatigue resistance exercise prior to endurance exercise should be avoided to prevent decreased performance in subsequent endurance performance. In addition, the quality of the “fastest repetition” during resistance exercise can be reduced when endurance exercise is performed prior to resistance exercise (Najera-Ferrer et al. 2021). As such, both endurance and strength training may significantly impair subsequent exercise performance. However, setting a moderate VL threshold (20% VL) for RT may avoid performing an excessive number of repetitions, which could compromise in a greater extent the quality of the subsequent endurance exercise (Najera-Ferrer et al. 2021). These findings are relevant for designing concurrent training schemes capable of reducing the fatigue accumulated between sequential sessions of resistance and endurance training. With regard to long-term adaptations, Sánchez-Moreno et al. (2021b) analyzed and compared the effects of three distinct 8-week training programs: an “isolated” endurance training program (ET) and two concurrent training schemes, which differed in the magnitudes of velocity loss within the RT sets: 15% (VL15) versus 45% (VL45) (Sánchez-Moreno et al. 2021b). Both concurrent training interventions produced greater gains in all strength-related variables and in jump height compared to the ET group. On the other hand, performing higher total volume during RT (VL45) did not elicit additional strength gains compared to the intervention that incurred a lower level of effort within the RT set (VL15). Furthermore, as expected, 8 weeks of isolated ET resulted in decreased strength performance (Sánchez-Moreno et al. 2021b). Lastly, although all groups improved certain endurance-related parameters (i.e., maximal aerobic speed; $v\text{VO}_{2\text{max}}$), notably, the VL15 group obtained greater increases than the ET group in these respective variables (Sánchez-Moreno et al. 2021b). Therefore, establishing moderate VL thresholds (i.e. VL15) during RT when combined with endurance training could be a good strategy for concomitantly

optimizing strength and endurance adaptations, as this probably results in reduced residual fatigue and increased training efficiency (when compared to higher magnitudes of VL; e.g., VL45) (Sánchez-Moreno et al. 2021b).

Table 3 Physiological and mechanical characteristics of four concurrent training protocols differing in the exercise sequence and the velocity loss incurred within the resistance exercise set

Variable	E + R20	E + R40	R20 + E	R40 + E	P-value protocol effect
Endurance training					
90% $\dot{V}O_2$ max (km·h ⁻¹)	14.1 ± 1.3	14.1 ± 1.3	14.1 ± 1.3	14.1 ± 1.3	1.00
Running time (s)	600 ± 0 ³	600 ± 0 ³	561 ± 70 ³	450 ± 131	0.002
HR peak (BPM)	180.7 ± 9.3	181.4 ± 9.9	184.1 ± 11.2	183.2 ± 8.4	0.06
Rel-HR peak (%)	96.5 ± 2.9	96.8 ± 2.1	98.2 ± 2.5	97.8 ± 2.1	0.07
$\dot{V}O_2$ peak (ml·kg ⁻¹ ·min ⁻¹)	48.5 ± 4.6	47.4 ± 5.6	48.1 ± 5.0	47.7 ± 7.7	0.90
Rel- $\dot{V}O_2$ peak (%)	90.5 ± 8.7	88.3 ± 9.6	89.5 ± 8.1	88.8 ± 14.1	0.86
RER peak	1.11 ± 0.05	1.11 ± 0.06	1.11 ± 0.06	1.08 ± 0.08	0.28
VE peak (l·min ⁻¹)	131.8 ± 15.8	129.3 ± 12.5	133.9 ± 14.6	134.6 ± 20.9	0.48
VE/ $\dot{V}O_2$ peak	35.1 ± 3.7	34.9 ± 3.2 ³	36.0 ± 3.2	37.3 ± 3.9	0.006
VE/ $\dot{V}CO_2$ peak	32.8 ± 3.1 ³	33.7 ± 3.0	34.2 ± 3.0	36.0 ± 3.5	0.007
Resistance training					
Load (kg)	63.1 ± 15.4	61.8 ± 14.7	61.5 ± 16.0	62.1 ± 13.8	0.74
Rep/Set (N)	9.1 ± 4.6 ^{1,3}	14.4 ± 6.0	10.0 ± 4.9 ^{1,3}	18.3 ± 9.0	0.001
Fastest-V (m·s ⁻¹)	0.96 ± 0.07	0.94 ± 0.07 ^{2,3}	1.00 ± 0.02	0.99 ± 0.02	0.04
Slowest-V (m·s ⁻¹)	0.76 ± 0.09 ^{1,3}	0.59 ± 0.09	0.82 ± 0.03 ^{1,3}	0.56 ± 0.05	<0.001
Mean-V (m·s ⁻¹)	0.85 ± 0.08 ^{1,3}	0.75 ± 0.07	0.88 ± 0.02 ^{1,3}	0.78 ± 0.04	<0.001
VL (%)	20.5 ± 2.9 ^{1,3}	36.1 ± 5.7	18.7 ± 2.4 ^{1,3}	36.9 ± 2.3	<0.001

Adapted from Najera-Ferrer et al. (2021). Data are expressed as mean ± standard deviation. E + R20: endurance (10 min at 90% $\dot{V}O_2$ max) + resistance (60% 1RM with 20% VL); E + R40: endurance (10 min at 90% $\dot{V}O_2$ max) + resistance (60% 1RM with 40% VL); R20 + E: resistance (60% 1RM with 20% VL) + endurance (10 min at 90% $\dot{V}O_2$ max); R40 + E: resistance (60% 1RM with 40% VL) + endurance (10 min at 90% $\dot{V}O_2$ max); 90% $\dot{V}O_2$ max: 90% of speed associated with the maximum oxygen uptake; running time: time that was maintained the endurance exercise protocol; HR peak: peak heart rate attained during the endurance exercise protocol; Rel-HR peak: peak heart rate, relative to maximum heart rate, attained during the endurance exercise protocol; $\dot{V}O_2$ peak: peak oxygen uptake attained during the endurance exercise protocol; Rel- $\dot{V}O_2$ peak: peak oxygen uptake, relative to maximal oxygen uptake, attained during the endurance exercise protocol; RER peak: peak respiratory exchange ratio attained during the endurance exercise protocol; VE peak: peak of ventilation volume attained during the endurance exercise protocol; VE/ $\dot{V}O_2$ peak: peak of ventilatory equivalent for oxygen attained during the endurance exercise protocol; VE/ $\dot{V}CO_2$ peak: peak of ventilatory equivalent for carbon dioxide attained during the endurance exercise protocol; Load: absolute load employed in the resistance exercise protocol; Rep/set: repetitions performed in each set; Fastest-V: highest velocity measured in the three sets; Slowest-V: lowest velocity measured in the three sets; Mean-V: mean velocity of all repetitions during the three sets; VL: mean percent loss in velocity over the three sets; Velocities correspond to the mean concentric propulsive velocity of each repetition. Statistically significant differences with E + R40 protocol: ¹P < 0.05. Statistically significant differences with R20 + E protocol: ²P < 0.05. Statistically significant differences with R40 + E protocol: ³P < 0.05

Muscular endurance is also a target of many training programs. In this regard, it has traditionally suggested that higher number of repetitions per set during RT should be completed to maximize improvements in this regard (Kraemer and Ratamess 2004; Campos et al. 2002). However, it has been observed that the gains in muscular endurance in the squat exercise—as assessed by the maximal number of repetitions with 70% 1RM until the lifting velocity falls below $0.50 \text{ m}\cdot\text{s}^{-1}$ —do not seem to depend exclusively on the total training volume accumulated. Indeed, after 8 weeks of a squat training program with loads ranging from 70 to 85% 1RM, both moderate and high magnitudes of VL led to similar increases in muscular endurance capacity (VL0: 70.9%; VL10: 100.2%; VL20: 103.8%; VL40: 96.3%). However, importantly, the VL40 group accumulated a substantially higher number of repetitions throughout the 8-week intervention (Pareja-Blanco et al. 2020a). Indeed, it appears that enhancements in muscular endurance depends, at least partially, on 1RM increments, since a significant relationship ($r = 0.63$) was previously reported between 1RM and muscular endurance changes in the squat exercise (Rodríguez-Rosell et al. 2020c). Moreover, some exercises, such as the pull-up, are often assessed on the basis of the MNR completed up to failure, using only the body mass as workload. Also for this exercise without additional overload, a training program with 25% of VL (VL25) resulted in greater gains in both pull-up strength and endurance compared to a training program with 50% of VL (VL50), despite the VL50 group performed more repetitions than VL25 (556 vs. 363 repetitions) across the entire training program (it is important to highlight that these extra repetitions were performed at low and very low velocities [$0.6\text{--}0.3 \text{ m}\cdot\text{s}^{-1}$]) (Sánchez-Moreno et al. 2020). The greater strength gains attained by VL25 group evoked that the relative intensity representing the body mass in pull-up for this group was reduced by 7% in relation to their maximum strength levels (from 70 to 63% of 1RM) (Sánchez-Moreno et al. 2020). In this sense, the greater increase observed in MNR by the VL25 group might be explained by the increase in muscle strength and, as a result, the decrease in the relative intensity (%1RM) represented by their BM, since the lower the relative intensity, the higher the MNR that can be performed. Therefore, even for “body-load exercises”, using a specific VL threshold during training programs can be an effective strategy to avoid performing an excessive number of deliberately slow and fatiguing repetitions which may even hamper training effectiveness.

5 Take-Home Messages

VBT is a novel practical, and effective training approach that provides coaches and researchers with accurate and immediate information regarding RT intensity, volume and RT effects. By means of VBT, it is possible to dictate and (re) adjust RT loads in real time, accounting for individual fluctuations in both strength and fatigue levels, which regularly occur on a set by set basis. The application of VL thresholds along with the concept of the level of effort attained during the set increases

substantially the efficiency of VBT, allowing practitioners to better and more precisely determine and achieve their training objectives. It is essential to understand that similar relative loads will result in different adaptations and responses to RT when different magnitudes of VL are being considered. Strength and conditioning coaches and sport scientists should use the information summarized here to create more effective VBT programs, taking into consideration that:

1. The very strong relationship that exists between relative load (%1RM) and movement velocity in multiple exercises allows the accurate determination of the 1RM value without the necessity of performing 1RM or XRM tests. This close and very stable relationship supports the use of VBT.
2. Higher VL thresholds within the set do not necessarily lead to superior adaptations in strength-related capacities and may even impair athletic performance by generating excessive degrees of fatigue.
3. The effort index has been shown to be strongly associated with distinct fatigue markers and, hence, can be used as a viable and additional tool for controlling and monitoring RT fatigue. However, it should be noted that the mechanisms underlying fatigue may differ between RT sessions with similar effort index but under different intensities and magnitudes of VL.
4. Recent evidence suggests that different VBT programming models lead to similar improvements in physical performance. This highlights the importance of properly defining and monitoring the magnitudes of relative loads and VL which, in essence, will determine the extent and directions of RT adaptations.

References

- Balsalobre-Fernández C, García-Ramos A, Jiménez-Reyes P (2018) Load–velocity profiling in the military press exercise: effects of gender and training. *Int J Sports Sci Coaching* 13(5):743–750
- Behm DG, Sale DG (1993) Intended rather than actual movement velocity determines velocity-specific training response. *J Appl (1985) Physiol* 74(1):359–368
- Benavides-Ubric A, Diez-Fernandez DM, Rodríguez-Perez MA, Ortega-Becerra M, Pareja-Blanco F (2020) Analysis of the load-velocity relationship in deadlift exercise. *J Sports Sci Med* 19(3):452–459
- Bird SP, Tarpenning KM, Marino FE (2005) Designing resistance training programmes to enhance muscular fitness: a review of the acute programme variables. *Sports Med* 35(10):841–851
- Bottinelli R, Canepari M, Pellegrino MA, Reggiani C (1996) Force-velocity properties of human skeletal muscle fibres: myosin heavy chain isoform and temperature dependence. *J Physiol* 495(Pt 2):573–586
- Braith RW, Graves JE, Leggett SH, Pollock ML (1993) Effect of training on the relationship between maximal and submaximal strength. *Med Sci Sports Exerc* 25(1):132–138
- Brzycki M (1993) Strength testing—predicting a one-rep max from reps-to-fatigue. *J Phys Edu Recreation Dance* 64(1):88–90
- Buckner SL, Jessee MB, Mattocks KT, Mouser JG, Counts BR, Dankel SJ et al (2017) Determining strength: a case for multiple methods of measurement. *Sports Med* 47(2):193–195

- Campos GE, Luecke TJ, Wendeln HK, Toma K, Hagerman FC, Murray TF et al (2002) Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol* 88(1–2):50–60
- Chapman PP, Whitehead JR, Binkert RH (1998) The 225–1b reps-to-fatigue test as a submaximal estimate of 1-RM bench press performance in college football players. *J Strength Conditioning Res* 12(4):258–261
- Conceicao F, Fernandes J, Lewis M, Gonzalez-Badillo JJ, Jimenez-Reyes P (2016) Movement velocity as a measure of exercise intensity in three lower limb exercises. *J Sports Sci* 34(12):1099–1106
- Cunanan AJ, DeWeese BH, Wagle JP, Carroll KM, Sausaman R, Hornsby WG 3rd et al (2018) The general adaptation syndrome: a foundation for the concept of periodization. *Sports Med* 48(4):787–797
- de Hoyo M, Nunez FJ, Borja S, Gonzalo-Skok O, Muñoz-López A, Romero-Boza S et al (2019) Predicting loading intensity measuring velocity in barbell hip thrust exercise. *J Strength Cond Res*
- Desmedt JE, Godaux E (1977) Ballistic contractions in man: characteristic recruitment pattern of single motor units of the tibialis anterior muscle. *J Physiol* 264(3):673–693
- Doma K, Deakin GB, Schumann M, Bentley DJ (2019) Training considerations for optimising endurance development: an alternate concurrent training perspective. *Sports Med* 49(5):669–682
- Dorrell HF, Smith MF, Gee TI (2020) Comparison of velocity-based and traditional percentage-based loading methods on maximal strength and power adaptations. *J Strength Cond Res* 34(1):46–53
- Eddens L, van Someren K, Howatson G (2018) The role of intra-session exercise sequence in the interference effect: a systematic review with meta-analysis. *Sports Med* 48(1):177–188
- Fernandes JFT, Lamb KL, Twist C (2018) A comparison of load-velocity and load-power relationships between well-trained young and middle-aged males during three popular resistance exercises. *J Strength Cond Res* 32(5):1440–1447
- Fry AC (2004) The role of resistance exercise intensity on muscle fibre adaptations. *Sports Med* 34(10):663–679
- Garcia-Pallares J, Izquierdo M (2011) Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Med* 41(4):329–343
- Garcia-Ramos A, Pestana-Melero FL, Perez-Castilla A, Rojas FJ, Haff GG (2018) Differences in the load-velocity profile between 4 bench-press variants. *Int J Sports Physiol Perform* 13(3):326–331
- Garcia-Ramos A, Suzovic D, Pérez-Castilla A (2019) The load-velocity profiles of three upper-body pushing exercises in men and women. *Sports Biomechanics* 1–13
- Goldberg AL, Etlinger JD, Goldspink DF, Jablecki C (1975) Mechanism of work-induced hypertrophy of skeletal muscle. *Med Sci Sports* 7(3):185–198
- Gonzalez-Badillo JJ, Sánchez-Medina L (2010) Movement velocity as a measure of loading intensity in resistance training. *Int J Sports Med* 31(5):347–352
- Gonzalez-Badillo JJ, Marques MC, Sánchez-Medina L (2011) The importance of movement velocity as a measure to control resistance training intensity. *J Hum Kinet* 29A:15–19
- Gonzalez-Badillo JJ, Rodriguez-Rosell D, Sánchez-Medina L, Gorostiaga EM, Pareja-Blanco F (2014) Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training. *Eur J Sport Sci* 1–10
- Gonzalez-Badillo JJ, Yanez-Garcia JM, Mora-Custodio R, Rodriguez-Rosell D (2017) Velocity loss as a variable for monitoring resistance exercise. *Int J Sports Med* 38(3):217–225
- Haff GG, Triplett NT (2015) *Essentials of strength training and conditioning*, 4th edn. Human Kinetics
- Harries SK, Lubans DR, Callister R (2015) Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength. *J Strength Cond Res* 29(4):1113–1125

- Hickson RC (1980) Interference of strength development by simultaneously training for strength and endurance. *Eur J Appl Physiol Occup Physiol* 45(2–3):255–263
- Izquierdo M, Gonzalez-Badillo JJ, Hakkinen K, Ibanez J, Kraemer WJ, Altadill A et al (2006) 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(9):718–724
- Kraemer WJ, Ratamess NA (2004) Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc* 36(4):674–688
- Loturco I, Ugrinowitsch C, Roschel H, Lopes Mellinger A, Gomes F, Tricoli V et al (2013) Distinct temporal organizations of the strength- and power-training loads produce similar performance improvements. *J Strength Cond Res* 27(1):188–194
- Loturco I, Pereira LA, Cal Abad CC, Gil S, Kitamura K, Kobal R et al (2016) Using bar velocity to predict the maximum dynamic strength in the half-squat exercise. *Int J Sports Physiol Perform* 11(5):697–700
- Loturco I, Kobal R, Moraes JE, Kitamura K, Cal Abad CC, Pereira LA et al (2017) Predicting the maximum dynamic strength in bench press: the high precision of the bar velocity approach. *J Strength Cond Res* 31(4):1127–1131
- Loturco I, Pereira LA, Freitas TT, Bishop C, Pareja-Blanco F, McGuigan MR (2021a) Maximum strength, relative strength, and strength deficit: relationships with performance and differences between elite sprinters and professional rugby union players. *Int J Sports Physiol Perform* 1–6
- Loturco I, Suchomel T, Kobal R, Arruda AFS, Guerriero A, Pereira LA et al (2021b) Force-velocity relationship in three different variations of prone row exercises. *J Strength Cond Res* 35(2):300–309
- Loturco I, McGuigan M, Freitas TT, Valenzuela P, Pereira LA, Pareja-Blanco F (2021c) Performance and reference data in the jump squat at different relative loads in elite sprinters, rugby players, and soccer players. *Biol Sport* 38(2):219–227
- Martinez-Cava A, Moran-Navarro R, Sánchez-Medina L, Gonzalez-Badillo JJ, Pallares JG (2019) Velocity- and power-load relationships in the half, parallel and full back squat. *J Sports Sci* 37(10):1088–1096
- Moran-Navarro R, Perez CE, Mora-Rodriguez R, de la Cruz-Sanchez E, Gonzalez-Badillo JJ, Sánchez-Medina L et al (2017) Time course of recovery following resistance training leading or not to failure. *Eur J Appl Physiol* 117(12):2387–2399
- Moran-Navarro R, Martinez-Cava A, Sánchez-Medina L, Mora-Rodriguez R, Gonzalez-Badillo JJ, Pallares JG (2019) Movement velocity as a measure of level of effort during resistance exercise. *J Strength Cond Res* 33(6):1496–1504
- Nagata A, Doma K, Yamashita D, Hasegawa H, Mori S (2020) The effect of augmented feedback type and frequency on velocity-based training-induced adaptation and retention. *J Strength Cond Res* 34(11):3110–3117
- Najera-Ferrer P, Perez-Caballero C, Gonzalez-Badillo JJ, Pareja-Blanco F (2021) Effects of exercise sequence and velocity loss threshold during resistance training on following endurance and strength performance during concurrent training. *Int J Sports Physiol Perform* 1–7
- Niewiadomski W, Laskowska D, Gąsiorowska A, Cybulski G, Strasz A, Langfort J (2008) Determination and prediction of one repetition maximum (1RM): safety considerations *J Hum Kinet* 19(1):109
- Ortega-Becerra M, Sánchez-Moreno M, Pareja-Blanco F (2021) Effects of cluster set configuration on mechanical performance and neuromuscular activity. *J Strength Cond Res* 35(2):310–317
- Pareja-Blanco F, Rodriguez-Rosell D, Sánchez-Medina L, Gorostiaga EM, Gonzalez-Badillo JJ (2014) Effect of movement velocity during resistance training on neuromuscular performance. *Int J Sports Med* 35(11):916–924
- Pareja-Blanco F, Rodriguez-Rosell D, Sánchez-Medina L, Sanchis-Moysi J, Dorado C, Mora-Custodio R et al (2017a) Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scand J Med Sci Sports* 27(7):724–735
- Pareja-Blanco F, Sánchez-Medina L, Suarez-Arrones L, Gonzalez-Badillo JJ (2017b) Effects of velocity loss during resistance training on performance in professional soccer players. *Int J Sports Physiol Perform* 12(4):512–519

- Pareja-Blanco F, Villalba-Fernandez A, Cornejo-Daza PJ, Sanchez-Valdepenas J, Gonzalez-Badillo JJ (2019) Time course of recovery following resistance exercise with different loading magnitudes and velocity loss in the set. *Sports* 7(3)
- Pareja-Blanco F, Alcazar J, Sánchez-Valdepeñas J, Cornejo-Daza PJ, Piqueras-Sanchiz F, Mora-Vela R et al (2020a) Velocity loss as a critical variable determining the adaptations to strength training. *Med Sci Sports Exerc* 52(8):1752–1762
- Pareja-Blanco F, Rodriguez-Rosell D, Aagaard P, Sánchez-Medina L, Ribas-Serna J, Mora-Custodio R et al (2020b) Time course of recovery from resistance exercise with different set configurations. *J Strength Cond Res* 34(10):2867–2876
- Pareja-Blanco F, Alcazar J, Cornejo-Daza PJ, Sanchez-Valdepenas J, Rodriguez-Lopez C, Hidalgo-de Mora J et al (2020c) Effects of velocity loss in the bench press exercise on strength gains, neuromuscular adaptations and muscle hypertrophy. *Scand J Med Sci Sports*
- Pareja-Blanco F, Walker S, Häkkinen K (2020d) Validity of using velocity to estimate intensity in resistance exercises in men and women. *Int J Sports Med* 41:1047–1055
- Perez-Castilla A, Garcia-Ramos A, Padial P, Morales-Artacho AJ, Feriche B (2018) Effect of different velocity loss thresholds during a power-oriented resistance training program on the mechanical capacities of lower-body muscles. *J Sports Sci* 36(12):1331–1339
- Pestana-Melero FL, Haff GG, Rojas FJ, Perez-Castilla A, Garcia-Ramos A (2018) Reliability of the load-velocity relationship obtained through linear and polynomial regression models to predict the 1-repetition maximum load. *J Appl Biomech* 34(3):184–190
- Reynolds JM, Gordon TJ, Robergs RA (2006) Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *J Strength Cond Res* 20(3):584–592
- Rhea MR, Ball SD, Phillips WT, Burkett LN (2002) A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *J Strength Cond Res* 16(2):250–255
- Rhea MR, Phillips WT, Burkett LN, Stone WJ, Ball SD, Alvar BA et al (2003) A comparison of linear and daily undulating periodized programs with equated volume and intensity for local muscular endurance. *J Strength Cond Res* 17(1):82–87
- Richens B, Cleather DJ (2014) The relationship between the number of repetitions performed at given intensities is different in endurance and strength trained athletes. *Biol Sport* 31(2):157–161
- Riscart-Lopez J, Rendeiro-Pinho G, Mil-Homens P, Soares-daCosta R, Loturco I, Pareja-Blanco F, Leon-Prados JA (2020) Effects of four different velocity-based training programming models on strength gains and physical performance. *J Strength Cond Res* (Epub Ahead of Print)
- Riscart-Lopez J, Rendeiro-Pinho G, Mil-Homens P, Soares-daCosta R, Loturco I, Pareja-Blanco F et al (2021) Effects of four different velocity-based training programming models on strength gains and physical performance. *J Strength Cond Res* 35(3):596–603
- Rodríguez-Rosell D (2017) Movement velocity as a critical variable for prescribing and monitoring resistance exercise, and as a determinant factor of the resistance training induced-adaptations. Doctoral dissertation, Supervised by Gonzalez-Badillo, JJ, Universidad Pablo de Olavide
- Rodriguez-Rosell D, Yanez-Garcia JM, Torres-Torrel J, Mora-Custodio R, Marques MC, Gonzalez-Badillo JJ (2018) Effort index as a novel variable for monitoring the level of effort during resistance exercises. *J Strength Cond Res* 32(8):2139–2153
- Rodriguez-Rosell D, Yanez-Garcia JM, Sánchez-Medina L, Mora-Custodio R, Gonzalez-Badillo JJ (2020a) Relationship between velocity loss and repetitions in reserve in the bench press and back squat exercises. *J Strength Cond Res* 34(9):2537–2547
- Rodriguez-Rosell D, Yanez-Garcia JM, Mora-Custodio R, Torres-Torrel J, Ribas-Serna J, Gonzalez-Badillo JJ (2020b) Role of the effort index in predicting neuromuscular fatigue during resistance exercises. *J Strength Cond Res*
- Rodriguez-Rosell D, Yanez-Garcia JM, Mora-Custodio R, Pareja-Blanco F, Ravelo-Garcia AG, Ribas-Serna J et al (2020c) Velocity-based resistance training: impact of velocity loss in the set on neuromuscular performance and hormonal response. *Appl Physiol Nutr Metab* (Epub Ahead of Print)

- Rodriguez-Rosell D, Martinez-Cava A, Yanez-Garcia JM, Hernandez-Belmonte A, Mora-Custodio R, Moran-Navarro R et al (2021) Linear programming produces greater, earlier and uninterrupted neuromuscular and functional adaptations than daily-undulating programming after velocity-based resistance training. *Physiol Behav* 113337
- Rontu JP, Hannula MI, Leskinen S, Linnamo V, Salmi JA (2010) One-repetition maximum bench press performance estimated with a new accelerometer method. *J Strength Cond Res* 24(8): 2018–2025
- Sánchez-Medina L (2010) Movement velocity as a determinant of the level of effort in resistance training. Doctoral dissertation, Supervised by Gonzalez-Badillo, JJ, Universidad Pablo de Olavide
- Sánchez-Medina L, Gonzalez-Badillo JJ (2011) Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Med Sci Sports Exerc* 43(9):1725–1734
- Sánchez-Medina L, Gonzalez-Badillo JJ, Perez CE, Pallares JG (2014) Velocity- and power-load relationships of the bench pull vs. bench press exercises. *Int J Sports Med* 35(3):209–216
- Sánchez-Medina L, Pallarés JG, Pérez CE, Morán-Navarro R, González-Badillo JJ (2017) Estimation of relative load from bar velocity in the full back squat exercise. *Sports Med Int Open* 01(02):E80–E88
- Sánchez-Moreno M, Rodriguez-Rosell D, Pareja-Blanco F, Mora-Custodio R, Gonzalez-Badillo JJ (2017) Movement velocity as indicator of relative intensity and level of effort attained during the set in pull-up exercise. *Int J Sports Physiol Perform* 12(10):1378–1384
- Sánchez-Moreno M, Cornejo-Daza PJ, Gonzalez-Badillo JJ, Pareja-Blanco F (2020) Effects of velocity loss during body mass prone-grip pull-up training on strength and endurance performance. *J Strength Cond Res* 34(4):911–917
- Sánchez-Moreno M, Rendeiro-Pinho G, Mil-Homens PV, Pareja-Blanco F (2021a) Monitoring training volume through maximal number of repetitions or velocity-based approach. *Int J Sports Physiol Perform* 1–8
- Sánchez-Moreno M, Rodriguez-Rosell D, Diaz-Cueli D, Pareja-Blanco F, Gonzalez-Badillo JJ (2021b) Effects of velocity loss threshold within resistance training during concurrent training on endurance and strength performance. *Int J Sports Physiol Perform* (Epub Ahead of Print)
- Schilling BK, Falvo MJ, Chiu LZ (2008) Force-velocity, impulse-momentum relationships: implications for efficacy of purposefully slow resistance training. *J Sports Sci Med* 7(2): 299–304
- Schiotz MK, Potteiger JA, Huntsinger PG, Donald C, Denmark LC (1998) The short-term effects of periodized and constant-intensity training on body composition, strength, and performance. *J Strength Conditioning Res* 12(3):173–178
- Schoenfeld BJ (2010) The mechanisms of muscle hypertrophy and their application to resistance training. *J Strength Cond Res* 24(10):2857–2872
- Schoenfeld BJ, Ogborn D, Krieger JW (2017) Dose-response relationship between weekly resistance training volume and increases in muscle mass: a systematic review and meta-analysis. *J Sports Sci* 35(11):1073–1082
- Scott BR, Duthie GM, Thornton HR, Dascombe BJ (2016) Training monitoring for resistance exercise: theory and applications. *Sports Med* 46(5):687–698
- Spiering BA, Kraemer WJ, Anderson JM, Armstrong LE, Nindl BC, Volek JS et al (2008) Resistance exercise biology: manipulation of resistance exercise programme variables determines the responses of cellular and molecular signalling pathways. *Sports Med* 38(7): 527–540
- Suchomel TJ, Nimphius S, Bellon CR, Stone MH (2018) The importance of muscular strength: training considerations. *Sports Med* 48(4):765–785
- Torrejón A, Balsalobre-Fernández C, Haff GG, García-Ramos A (2019) The load-velocity profile differs more between men and women than between individuals with different strength levels. *Sports Biomechanics* 18(3):245–255
- Weakley J, Ramirez-Lopez C, McLaren S, Dalton-Barron N, Weaving D, Jones B et al (2019a) The effects of 10%, 20%, and 30% velocity loss thresholds on kinetic, kinematic, and repetition characteristics during the Barbell Back Squat. *Int J Sports Physiol Perform* 1–9

Weakley JJS, Wilson KM, Till K, Read DB, Darrall-Jones J, Roe GAB et al (2019b) Visual feedback attenuates mean concentric barbell velocity loss and improves motivation, competitiveness, and perceived workload in male adolescent athletes. *J Strength Cond Res* 33(9):2420–2425

Williams TD, Toluoso DV, Fedewa MV, Esco MR (2017) Comparison of periodized and non-periodized resistance training on maximal strength: a meta-analysis. *Sports Med* 47(10): 2083–2100



Fernando Pareja-Blanco is graduated in Physical Activity and Sports Science and holder of a Doctorate from the Pablo de Olavide University (UPO) of Seville, where, under the supervision of Professor Juan José González-Badillo, he wrote his Doctoral Thesis “Movement velocity as a determining factor in the adaptations brought through resistance training.” He has published over 70 scientific articles in JCR journals in the Sports Science section one book and two book chapters, developing his scientific career at the Physical Performance and Sports Research Center at the UPO. He has spent periods working with researchers of international prestige, as Prof. José Antonio López Calbet (University of Las Palmas de Gran Canaria, Spain), Prof. Per Aagaard (Southern Denmark University, Denmark), Prof. Keijo Hakkinen (University of Jyväskylä, Finland), and Ph.D. Irineu Loturco (Nucleus of High Performance; Brazil). He is

currently an associate professor at the Faculty of Sport Sciences at UPO. From a practical point of view, he has worked as strength and conditioning consulting in different athletic modalities, such as soccer, basket, tennis, track and field, volleyball, swimming, rugby, taekwondo, weightlifting, and fencing, among others.



Irineu Loturco has a Ph.D. in sport science at the Pablo de Olavide University (UPO) of Seville and a postdoctoral degree in Mechatronics Engineering and Mechanical Systems at the Polytechnic School of the University of São Paulo. He is the director of the Nucleus of High Performance in Sport (NAR; São Paulo, Brazil), a high-performance training center that serves hundreds of top-level athletes from many different sports. He has worked as a strength and conditioning coach in major Brazilian soccer clubs and with different Olympic and Paralympic sports, especially national teams. Currently, he is a professor of Methodology of Sports Training at the Federal University of São Paulo (UNIFESP) and a visiting professor at the University of South Wales, in Pontypridd, UK. During his academic career, he has published more than 160 peer-reviewed articles. The vast majority of his studies involve professional athletes, many of them competing at the Olympic level.