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Resistance training intensity prescription methods based on lifting velocity monitoring

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Abstract:
Resistance training intensity is commonly quantified as the load lifted relative to an individual's maximal dynamic strength. This approach, known as percent-based training, necessitates evaluating the one-repetition maximum (1RM) for the core exercises incorporated in a resistance training program. However, a major limitation of rigid percent-based training lies in the demanding nature of directly testing the 1RM from technical, physical and psychological perspectives. A potential solution that has gained popularity in the last two decades to facilitate the implementation of percent-based training involves the estimation of the 1RM by recording the lifting velocity against submaximal loads. This review examines the three main methods for prescribing relative loads (%1RM) based on lifting velocity monitoring: (i) velocity zones, (ii) generalized load-velocity relationships, and (iii) individualized load-velocity relationships. The article concludes by discussing a number of factors that should be considered for simplifying the testing procedures while maintaining the accuracy of individualized L-V relationships to predict the 1RM and establish the resultant individualized %1RM-velocity relationship: (i) exercise selection, (ii) type of velocity variable, (iii) regression model, (iv) number of loads, (v) location of experimental points on the load-velocity relationship, (vi) minimal velocity threshold, (vii) provision of velocity feedback, and (viii) velocity monitoring device.

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Resistance training intensity prescription methods based on lifting velocity monitoring

ABSTRACT

Resistance training intensity is commonly quantified as the load lifted relative to an individual's maximal dynamic strength. This approach, known as percent-based training, necessitates evaluating the one-repetition maximum (1RM) for the core exercises incorporated in a resistance training program. However, a major limitation of rigid percent-based training lies in the demanding nature of directly testing the 1RM from technical, physical and psychological perspectives. A potential solution that has gained popularity in the last two decades to facilitate the implementation of percent-based training involves the estimation of the 1RM by recording the lifting velocity against submaximal loads. This review examines the three main methods for prescribing relative loads (%1RM) based on lifting velocity monitoring: (i) velocity zones, (ii) generalized load-velocity relationships, and (iii) individualized load-velocity relationships. The article concludes by discussing a number of factors that should be considered for simplifying the testing procedures while maintaining the accuracy of individualized L-V relationships to predict the 1RM and establish the resultant individualized %1RM-velocity relationship: (i) exercise selection, (ii) type of velocity variable, (iii) regression model, (iv) number of loads, (v) location of experimental points on the load-velocity relationship, (vi) minimal velocity threshold, (vii) provision of velocity feedback, and (viii) velocity monitoring device.

Keywords: autoregulation; linear position transducer; load-velocity relationship; one-repetition maximum: strength; velocity-based training.

1. Introduction

Physiological responses to resistance training (RT) and the resulting adaptations depend on various RT variables such as the exercise type and order, exercise intensity, volume, inter- and intra-set rest periods, and lifting tempo [1]. Among these variables, exercise intensity (load lifted relative to an individual's maximal strength) is likely the most critical factor for promoting strength gains [2]. Therefore, to achieve specific RT adaptations, it is essential for coaches and researchers to have reliable references to individualize the loads. Coaches primarily rely on the one-repetition maximum (1RM), which represents the heaviest load that can be lifted with proper technique for a single repetition in a given exercise, as the main reference for load individualization [3].

Traditionally, absolute loads (kg) have been assigned to match a specific relative load (%1RM) that needs to be lifted for a predetermined number of sets and repetitions [1]. This approach, known as percent-based training, establishes target intensities and volumes at the beginning of the training cycle. The traditional approach requires the direct assessment of the 1RM at the onset of the training cycle for the core exercises incorporated in the RT program. Subsequently, loads are prescribed relative to the individual's maximal dynamic strength (e.g., 75%1RM), and coaches need to make the assumption that 1RMs remain stable or increase by a fixed amount throughout the training cycle. However, it is well-known that RT adaptations are subject-specific, resulting in significant inter-subject variability in 1RM changes to the same RT program [4]. This variability poses a problem when using the rigid percent-based prescription method, as in many instances, the prescribed load may not match the intended %1RM.

To ensure a closer match between the intended and delivered RT stimulus, several autoregulation methods have been proposed [5, 6]. Autoregulation in RT refers to the process that allows practitioners to continuously adjust training variables based on the measurement of an individual's performance or their perceived ability to perform. Unlike the rigid percent-based approach, autoregulation methods enable the adjustment of training variables, such as the load lifted or the number of sets and repetitions, on a daily basis according to athletes' feedback on their physical performance. The feedback can be either subjective (e.g., ratings of perceived exertion) or objective (e.g., lifting velocity) [5, 6]. Therefore, autoregulation methods take into account both the individual responses to training (i.e., rate of progress) and non-training-related stressors (e.g., sleep, nutrition, and life stress).

Velocity-based training (VBT) is an objective autoregulation method that has gained popularity among sport scientists and practitioners due to the proliferation of devices that accurately monitor movement velocity during RT exercises [7, 8]. VBT has important applications for (i) enhancing training quality, (ii) prescribing RT intensities and volumes, and (iii) assessing day-to-day physical readiness and training-induced neuromuscular adaptations [7]. This review article focuses exclusively on one of the multiple applications of VBT: prescribing RT intensities. More specifically, the article examines the three main methods that have been proposed to prescribe loads to match specific RT intensities (%1RM) based on lifting velocity monitoring: (i) velocity zones, (ii) generalized load-velocity (L-V) relationships, and (iii) individualized L-V relationships. Finally, due to the proven superiority of individualized L-V relationships [7], the article concludes by addressing a number of factors influencing its accuracy to estimate the 1RM, including exercise selection, type of velocity variable, regression model,

number of loads, location of experimental points on the L-V relationship, minimal velocity threshold (MVT), provision of velocity feedback, and velocity monitoring device.

2. Direct assessment of the 1RM

The direct assessment of the 1RM is acknowledged as a valuable method for evaluating an individual's maximal strength capacity, offering significant applications in both training and testing contexts [3]. The standard procedure involves performing a specific exercise with increasing loads until reaching the maximum lifting capacity, considering the test complete when individuals can no longer perform a successful repetition with a higher load. Achieving accurate (maximal) results while minimizing the risk of injury requires meticulous attention to proper form, focused concentration, and a competitive mindset.

The direct 1RM test offers advantages and limitations. Notably, it exhibits superior face validity and reproducibility compared to 1RM estimation methods [3, 9]. However, the direct assessment of 1RM is physically, technically, and psychologically demanding. Physically, exercises involving large muscle groups or requiring high technical proficiency can be particularly challenging. There is also a potential risk of injury if proper form is not maintained during maximal lifts. Moreover, attempting maximal lifts can be intimidating for some individuals, potentially leading to decreased performance or reluctance to push beyond their comfort zone. Furthermore, the 1RM can fluctuate due to non-training-related stressors (e.g., sleep, nutrition, and life stress) or systematically change due to training or detraining. Therefore, frequent 1RM assessments may be necessary to ensure a closer match between the intended and delivered relative load (%1RM). All these limitations may lead coaches to discard the use of the 1RM as a reference for individualizing training loads despite its unquestionable value.

Lifting velocity monitoring against submaximal loads has been proposed as a substitute of maximal 1RM tests. However, even for coaches and researchers who choose to retain the direct 1RM test, monitoring lifting velocity can still be valuable to refine their testing procedures. The most useful application of lifting velocity monitoring is to inform whether the tested loads represent true maximums or not. A general MVT, which represents the mean velocity attained at the 1RM trial, has been proposed for commonly used RT exercises [7]. Based on this information, a true 1RM could be considered valid only when the mean lifting velocity, assuming maximal intent during the repetition, is lower or comparable to the MVT associated with the tested exercise. Considering this information coaches can make more informed decisions on whether athletes should attempt further lifts during 1RM testing sessions [10].

3. Indirect assessment of the 1RM and relative loads (%1RM) through lifting velocity

The unquestionable importance of the 1RM, coupled with the limitations associated with its direct assessment, justifies the interest on exploring 1RM estimation methods. The two most popular approaches for estimating 1RM include (i) repetitions-to-failure tests [11], and (ii) lifting velocity monitoring against submaximal loads [7]. Repetitions-to-failure tests were introduced earlier due to their ease of implementation, as they do not require sophisticated equipment, making them suitable for widespread use in various training environments [11]. However, since the fatigue induced by performing repetitions until muscular failure can interfere with training goals [12], a less prone to fatigue method based on lifting velocity monitoring has recently gained popularity in the strength and conditioning field. Notably, recent research has evidenced

that lifting velocity can provide estimates of 1RM with comparable or potentially greater accuracy than repetitions-to-failure tests [13–15]. This section discusses the three main methods proposed for prescribing absolute loads (kg) to match specific relative loads (%1RM) based on lifting velocity monitoring, starting from the least to the most accurate: (i) velocity zones, (ii) generalized L-V relationships, and (iii) individualized L-V relationships.

3.1 Velocity zones

Velocity zones refer to predetermined ranges of lifting velocities that are utilized to target specific qualities of strength and guide load selection (**Figure 1**). Velocity zones were introduced by Bryan Mann [16] and they were apparently supported by a strong and consistent relationship between barbell mean lifting velocity and the intensity of the load lifted (%1RM) for the squat and deadlift exercises in collegiate athletes. These velocity zones were subsequently generalised to other exercises. Consequently, rather than prescribing the loads to match a specific %1RM, coaches were encouraged to assign loads based on the corresponding velocity range. Note that initiating the sets within a specific range of lifting velocities implies that, regardless of the exercise and athlete's characteristics, the load intensity lifted (%1RM) is assumed to be practically identical.

[Figure 1]

However, it is crucial to acknowledge that each exercise has a distinct %1RM-velocity profile, and thus generalizing velocity zones across different exercises may not be valid. **Figure 2** illustrates the generalized %1RM-velocity relationship reported in previous studies for five specific exercises such as the squat [17], deadlift [18], bench press [19], bench pull [20], and pull-up [21]. Note that a fixed velocity value of 0.50 $m \cdot s^{-1}$ would correspond to different relative loads for the squat (≈ 78%1RM), deadlift (≈ 89%1RM), bench press (≈ 77%1RM), bench pull (≈ 97%1RM), and pull-up (≈ 84%1RM). This highlights that when the same initial velocity is prescribed, athletes will be likely experiencing different levels of effort depending on the exercise performed. A more comprehensive and individualized approach to VBT that accounts for the unique characteristics of each exercise is required.

[Figure 2]

3.2 Generalized load-velocity relationships

The generalized L-V relationship was introduced by González-Badillo and Sánchez-Medina [19]. The conventional procedure for establishing a generalized L-V relationship involves recruiting a significant number of subjects to complete a full incremental loading test in a specific exercise. The test starts with a light load and the load is progressively increased until reaching the 1RM. The velocity output of the fastest repetition performed with each load by each subject is used for subsequent analyses. Once the 1RM load is known, the absolute loads (kg) are expressed as relative loads (%1RM). Therefore, each subject contributes multiple experimental points, with each point representing a relative load (%1RM) and its corresponding velocity value. Finally, a linear (in some studies a second-order polynomial) regression model is applied to the experimental points provided by all subjects to establish the generalized (i.e., averaged across the subjects) relationship between %1RM and lifting velocity. Generalized L-V relationships have been established for a variety of RT exercises, including the squat [17, 22,

23], deadlift [18, 24, 25], hip-thrust [26, 27], leg press [23, 28], leg extension [29], bench press [19, 30–32], bench pull [20, 30, 33], military press [34–37], and pull-up [21, 38]. The ultimate goal of generalized L-V relationships is *"to determine what is the %1RM that is being used as soon as the first repetition with a given load is performed with maximal voluntary velocity"* [19].

Table 1 presents the mean velocity values corresponding to various %1RMs for young and healthy males obtained in commonly employed RT exercises. Exercise-specific generalized L-V relationships represent a notable improvement over universal velocity zones since they take into account the unique characteristics of each exercise. However, it is not rare to observe discrepancies across studies examining the same %1RM-velocity relationship. For instance, the mean propulsive velocity associated with the 50%1RM during the full squat exercise was reported as 1.14 $m \cdot s^{-1}$ by Sánzhez-Medina et al. [22], 0.99 $m \cdot s^{-1}$ by Conceição et al. [23], and 0.84 $m \cdot s^{-1}$ by Martínez-Cava et al. [17]. In other words, a repetition performed at a mean propulsive velocity of 0.70 $m \cdot s^{-1}$ would correspond to the 79%1RM for Sánzhez-Medina et al. [22], 72%1RM for Conceição et al. [23], and 64%1RM for Martínez-Cava et al. [17]. These discrepancies could be especially problematic considering that the three studies tested a similar sample (young healthy males) using the same equipment (Smith machine) and velocity monitoring device (T-Force System, Ergotech, Murcia, Spain). It must be noted that the universal adoption of generalized L-V relationships is limited by at least seven additional problems, which include the variant-specific, sex-specific, age-specific, device-specific, equipment-specific, subject-specific, and training-specific nature of %1RM-velocity relationships.

[Table 1]

Problem 1 – The %1RM-velocity relationship is variant-specific

Modifications to the exercise, such as incorporating the stretch-shortening cycle, performing the exercise in a ballistic fashion, or altering the range of motion, can all significantly influence the %1RM-velocity relationship. Namely, greater velocities for the same %1RMs have been reported during the squat and bench press exercises when (i) utilizing the stretch-shortening cycle compared to the concentric-only execution [31, 39–41], (ii) adopting the ballistic variant (jump squat or bench press throw) compared to the non-ballistic variant [31, 39], and (iii) increasing the range of motion [17, 32]. The differences were accentuated at light relative loads, and they gradually diminished and eventually vanished at or very close to the 1RM.

Problem 2 – The %1RM-velocity relationship is sex-specific

Men exhibit greater velocities at the same relative loads (%1RM) than women. These findings have been reported across various exercises, including the squat, deadlift, hip thrust, horizontal and inclined leg press, horizontal and inclined bench press, seated chest press, and seated military press [27, 28, 34, 36, 42–46]. Notably, the disparities between men and women are more pronounced when using lighter relative loads and gradually diminish as the relative load increases.

Problem 3 – The %1RM-velocity relationship is age-specific

The %1RM-velocity relationship exhibits a flattened slope with advancing age, attributed to the phenomenon of younger individuals demonstrating greater velocity values than their older

counterparts at light relative loads, while the differences gradually decrease with increasing relative loads. This observation was directly supported by Fernandes et al. [47] in a study comparing young (21.0 ± 1.6 years) and middle-aged (42.6 ± 6.7 years) males during the bench press, squat, and bent-over-row exercises. Indirect evidence can also be obtained by comparing the generalized load-velocity (L-V) relationships reported by Marcos-Pardo et al. [48] for elderly women (68.2 ± 3.6 years) during the bench press and inclined leg press with the generalized L-V relationships reported in other studies for young women [28, 36, 42, 44].

Problem 4 – The %1RM-velocity relationship is device-specific
Systematic bias in mean velocity values has been observed across various devices commonly used to measure movement velocity during RT [8, 49–53]. These findings indicate that generalized L-V relationships may also be contingent upon the choice of measurement tools. Therefore, when coaches employ a velocity monitoring device that differs from the one utilized in the study where the generalized L-V relationship was proposed, a reduced accuracy when prescribing the relative loads based on velocity recordings is expected.

Problem 5 – The %1RM-velocity relationship is equipment-specific
The generalized L-V relationship has been demonstrated to be altered in specific contexts, such as the deadlift exercise when utilizing lifting straps [18], and during the bench press when performed using a Smith machine compared to using a weight stack machine [54] or free-weights [55]. As a result, it is not surprising that researchers have frequently recommended specific L-V relationship equations for each exercise mode [54, 55].

Problem 6 – The %1RM-velocity relationship is subject-specific
Multiple studies have unequivocally demonstrated the individual nature of %1RM-velocity profiles [9, 20, 28, 56–63]. Consistent findings provide irrefutable proof that individuals who exhibit higher velocities for a given %1RM during a specific exercise also tend to demonstrate higher velocities for the same %1RMs when the L-V relationship is assessed on separate occasions [20, 56, 57, 63]. Key statistical measures employed to validate the existence of subject-specific %1RM-velocity profiles include significant and positive associations (e.g., Pearson's or intraclass correlation coefficients) and lower within-subject variability compared to between-subject variability for the velocity corresponding to various %1RMs.

Problem 7 – The %1RM-velocity relationship is training-specific
Three studies suggested that the velocities corresponding to different %1RMs remain stable following conventional RT programs of 6 weeks for the bench press [19], 12 weeks for the pull-up [21], and 10 weeks for the shoulder press [37]. However, speed-oriented RT programs have shown different results. Cluster set configurations over 5 weeks [61] and light-load ballistic training over 4 weeks [62] resulted in significant increases in velocity at light relative loads during the squat and bench press exercises in healthy young subjects. Similarly, Ni and Signorile [64] informed significant changes in the %1RM-velocity relationship in patients with Parkinson's disease following a 12-week high-speed RT program involving exercises such as the biceps curl, chest press, leg press, hip abduction, and seated calf. These findings suggest the importance of periodically calibrating the individualized L-V relationship to account for training adaptations.

3.3 Individualized load-velocity relationships

Table 2 provides a description of the three most commonly used approaches for establishing the individual relationship between the relative load (%1RM) and lifting velocity. The first two approaches involve a direct assessment of the 1RM, while the third approach eliminates the need for direct assessment by estimating the 1RM as the load corresponding to a specific MVT. Since one of the main advantages of VBT is the avoidance of maximal tests, this section will focus exclusively on the approach that does not require a direct 1RM assessment (**Figure 3**). Note that other approaches such as the load at zero velocity [65] and force-velocity method [66] have also been proposed, but they will not be discussed as they have received less scientific attention.

[Table 2]
[Figure 3]

It is important to note that individualized L-V relationships have faced criticism compared to velocity zones or generalized L-V relationships due to the perception that they require a more time-consuming, fatiguing, and complex testing procedure. For example, Jovanovic & Flanagan [10] originally proposed a method that involved recording mean lifting velocity over at least 4-6 increasing loads and performing a set of repetitions to failure to determine the individual MVT based on the mean velocity of the last repetition. However, this approach is impractical for daily use. Shorter and less fatiguing procedures have been developed to facilitate the implementation of individualized L-V relationships, such as the use of the 2-point method (i.e., recording mean velocity against only 2 loads) or using an exercise-specific general MVT [7]. This review concludes by highlighting 8 factors that should be considered when modelling individualized L-V relationships to predict the 1RM and establish the resultant individualized %1RM-velocity relationship. Recommendations are provided to implement the testing procedures with minimal time and effort while maximizing accuracy.

Factor 1 – Exercise selection

Although lifting velocity can be recorded against submaximal loads with high and comparable reliability during both upper- and lower-body exercises [67–71], individualized L-V relationships have demonstrated superior accuracy in predicting the 1RM for upper-body (e.g., bench press or bench pull) compared to lower-body (e.g., squat or deadlift) exercises [14, 72–75]. The varying accuracy in 1RM predictions is likely due to the 1RM being influenced not only by intrinsic capacities of the muscles to produce maximal levels of force, but also by lifting technique and psychological factors such as motivation and discomfort tolerance. Lower-body exercises are generally more technically demanding and physically challenging, which may explain the lower accuracy of individualized L-V relationships in predicting the 1RM for these exercises. However, we hope that by utilizing the optimal MVT (as discussed in factor 6), this issue can be potentially addressed. It is plausible that individuals with better lifting technique and greater tolerance to discomfort during 1RM attempts may benefit from using lower MVTs compared to those with poorer lifting technique or phycological mindset.

Factor 2 – Type of velocity variable

The use of mean velocity, which represents the average velocity throughout the entire concentric phase, is generally preferred when modelling the individualized L-V relationship compared to other velocity variables like mean propulsive velocity (average velocity from the start of the concentric phase until acceleration drops below -9.81 m/s^2) or peak velocity (maximum

instantaneous velocity attained during the concentric phase). This preference is justified by the stronger linearity observed in the L-V relationship and the higher between-day reliability of mean velocities corresponding to different %1RMs [14, 20, 57]. Olympic lifts may be an exception for which peak velocity could be more appropriate [76].

Factor 3 – Regression model

The simple linear regression model is recommended over curvilinear regression models, such as the commonly used second-order polynomial regression, due to its superior accuracy and reliability in estimating the 1RM and velocities associated with different relative loads [56, 75]. It is worth noting that some studies have favoured the second-order polynomial regression model due to its better goodness-of-fit to the experimental data (i.e., greater r^2 values) [19, 22]. However, it is important to keep in mind that a higher r^2 value does not necessarily guarantee greater reliability and accuracy in obtaining the final outcomes of individualized L-V relationships.

Factor 4 – Number of loads

The same regression line (i.e., intercept and slope) and its derived outcomes (e.g., load corresponding to the MVT) are expected to be obtained when two linearly related variables, such as load (kg or %1RM) and velocity, are collected under two (two-point method) or more than two (multiple-point method) loading conditions [77]. There is compelling evidence showing that the individualized L-V relationship modelled by the two-point method, provided that the heaviest load is the same for both methods, can provide a prediction of the 1RM equally valid as the multiple-point method [14, 74, 75, 78, 79]. Therefore, the two-point method has the potential to simplify (saving time and reducing fatigue) testing procedures. It should be noted that a recent systematic review has recommended maximizing the number of loads to enhance the reliability and validity of 1RM predictions from individualized L-V relationships [80]. However, this recommendation may be biased, as the heaviest load was generally closer to the 1RM for the models using more loads.

Factor 5 – Location of the experimental points on the L-V relationship

The accuracy of the L-V relationship in estimating the 1RM declines as the distance from the experimental point corresponding to the heaviest load to the MVT represented by the 1RM increases [9, 72, 73, 81, 82]. When using the individualized L-V relationship to estimate the 1RM, it is crucial to have one experimental point (heaviest load) close to the MVT (mean velocity difference < 0.30 $m \cdot s^{-1}$), while another experimental point (lightest load) should allow for a mean velocity 0.40-0.60 $m \cdot s^{-1}$ faster than the heaviest load [81]. The 0.40-0.60 $m \cdot s^{-1}$ difference ensures a consistent slope of the L-V relationship [77], while avoiding excessively light loads (< 40%1RM) that may yield less reliable velocity outputs [70]. Intermediate loads can be considered between the two most distal experimental points but they are not expected to meaningfully influence the predicted 1RM value [77].

Factor 6 – Minimal velocity threshold (MVT)

The MVT traditionally represents the mean concentric velocity achieved during the 1RM trial or the last successful repetition of a set performed to failure [83]. The MVT is exercise-specific [7, 84]. While it has been argued that lower-body exercises may produce higher MVTs compared to upper-body exercises due to a larger range of motion [16], significant variations in MVTs have

been reported for exercises with similar ranges of motion, such as the bench press (MVT = 0.17 $m \cdot s^{-1}$) and bench pull (MVT = 0.50 $m \cdot s^{-1}$). In this regard, it is plausible that exercises allowing for a greater lifting distance to be completed before encountering the sticking region may exhibit higher MVT values.

When predicting the 1RM through the individualized L-V relationship, researchers have employed either the same exercise-specific MVT for all subjects (general MVT) or the individual mean velocity attained during the 1RM trial or last repetition of a set to failure (individual MVT) [9, 72–75, 85]. The individual MVT has demonstrated low reliability [36, 72, 73, 83], while the between- and within-subject variability of the individual MVT have been found to be comparable [56]. In addition, studies comparing the precision of 1RM estimation between individual and general MVTs failed to show significant differences [74, 75, 85]. As a result, the general MVT has been recommended over the individual MVT as it eliminates the need for maximal testing. However, strong evidence, particularly for lower-body exercises such as the squat or deadlift, indicates that both general and individual MVTs can significantly overestimate or underestimate the 1RM [72, 73, 86]. The optimal MVT (MVT that minimizes the differences between the actual and predicted 1RM when both are obtained in the same test) has been recently proposed to further improve the accuracy of 1RM estimation [81]. Using the optimal MVT in subsequent sessions may enhance the precision of 1RM estimation compared to the general and individual MVTs. The superiority of the optimal MVT has been already demonstrated for predicting the Smith machine bench press 1RM [81], but further studies are needed to confirm its potential advantages for other RT exercises.

Factor 7 – Provision of velocity feedback

Augmented feedback of lifting velocity should be provided immediately after performing each repetition to increase subjects' motivation, optimize mechanical performance, and maximize data consistency [87, 88]. The provision of velocity feedback was shown as an effective strategy to increase the accuracy of the individualized L-V relationship to estimate the free-weight bench press 1RM [88].

Factor 8 – Velocity monitoring device

Linear position transducers are widely recognized as the gold-standard technology for implementing the different applications of VBT [8]. Of note is that different studies have revealed systematic bias in mean velocity values across various linear position transducers [49–53]. However, the only study that directly compared the accuracy of individualized L-V relationships to estimate the 1RM among different brands of linear position transducers found similar levels of accuracy across all devices [79]. This suggests that any device capable of providing mean velocity outputs with high reliability and validity can be confidently utilized to estimate the 1RM using the individualized L-V relationship.

4. Conclusions

The 1RM is a crucial parameter for both training and testing purposes. Its assessment not only informs appropriate loading prescriptions for effective training but also serves as a valuable tool for evaluating progress, setting goals, and establishing benchmarks in various athletic and research contexts. However, the direct assessment of 1RM is physically, technically, and psychologically demanding, which may lead some coaches to discard the 1RM as a reference for

individualizing training loads despite its unquestionable value. A potential solution that has gained popularity in the last two decades involves estimating the relative loads (1RM or %1RM) by recording the lifting velocity against submaximal loads. Three different methods have been proposed to prescribe loads to match specific RT intensities (%1RM) based on lifting velocity monitoring: (i) velocity zones, (ii) generalized L-V relationships, and (iii) individualized L-V relationships. Individualized L-V relationships are widely regarded as superior due to the specific nature of %1RM-velocity relationships, which are influenced by factors such as the exercise type, exercise variant, sex, age, velocity monitoring device, equipment used, subject characteristics, and the individual's recent training history. A number of factors should be considered to simplify the testing procedures while maintaining a high accuracy when utilizing the individualized L-V relationship to predict the 1RM and establish the resultant individualized %1RM-velocity relationship. These factors include the exercise selection, type of velocity variable, regression model, number of loads, location of experimental points on the L-V relationship, MVT, provision of velocity feedback, and velocity monitoring device.

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TABLE CAPTIONS

Table 1. Mean velocity values ($m \cdot s^{-1}$) corresponding to various relative loads (%1RM) reported in the scientific literature for young healthy males.

Table 2. Analysis of the three commonly used approaches to establish the individual relationship between the relative load (%1RM) and lifting velocity.

FIGURE LEGENDS

Figure 1. Universal velocity zones originally proposed to induce adaptations in specific physical traits.

Figure 2. Generalized load-velocity relationships reported in previous studies for the squat (17), deadlift (18), bench press (19), bench pull (20), and pull-up (21) exercises. Note that the same velocity zones represent different ranges of relative loads for each exercise. 1RM, one-repetition maximum.

Figure 3. Illustration of an Excel spreadsheet that can be used for estimating the one-repetition maximum (1RM) and mean velocities associated with different relative loads (%1RM) through two simple steps: (i) recording the mean velocity against at least two different external loads, and (ii) indicating the value of the minimal velocity threshold (MVT).

Table 1. Mean velocity values ($m \cdot s^{-1}$) corresponding to various relative loads (%1RM) reported in the scientific literature for young healthy males.

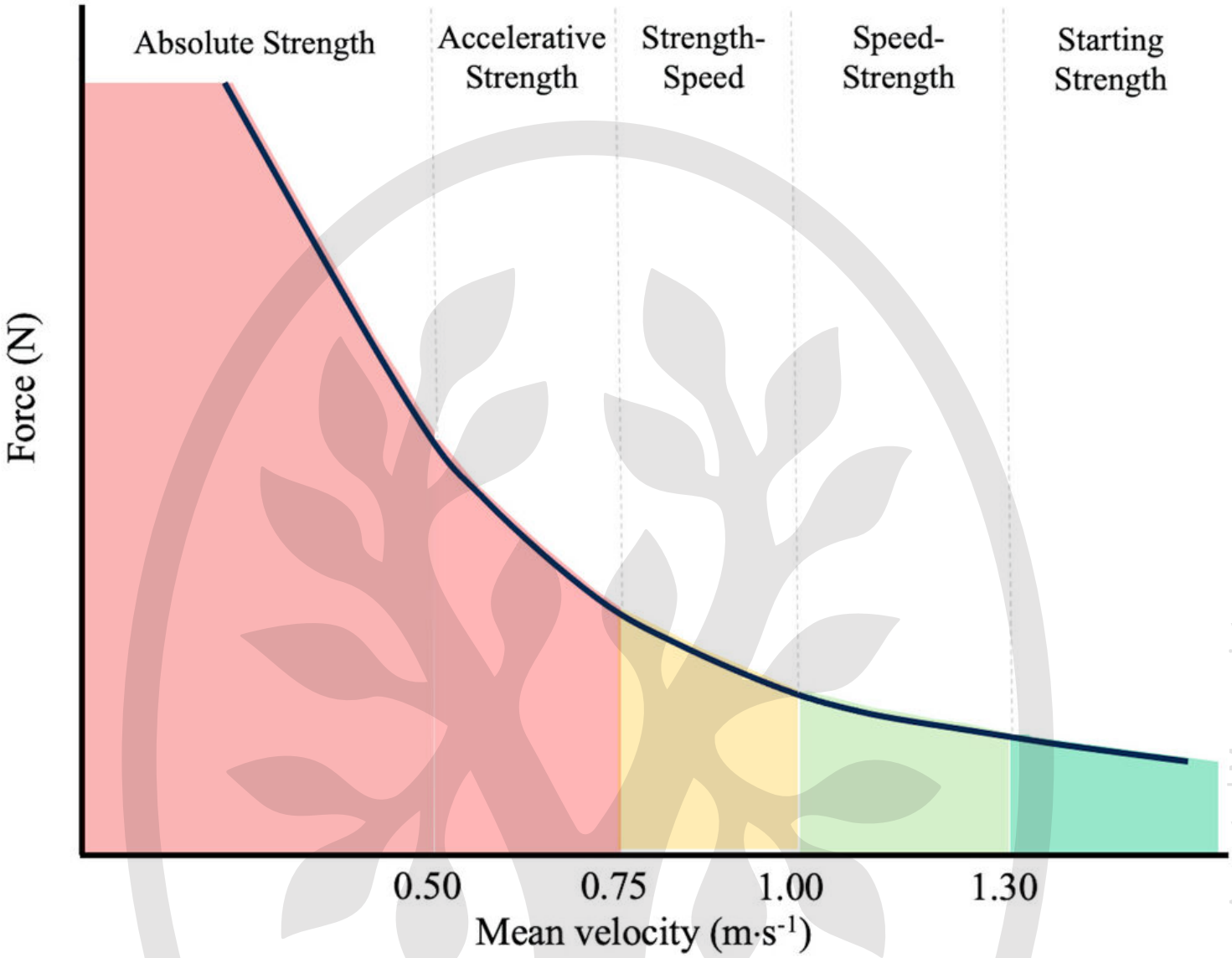
Sample	Exercise	Relative load (%1RM)						
		40%	50%	60 %	70%	80%	90%	100%
N = 132 from two studies [17, 22]	Full squat	1.08	0.97	0.86	0.74	0.60	0.46	0.31
N = 52 from one study [17]	Parallel squat	0.85	0.75	0.66	0.57	0.49	0.40	0.31
N = 52 from one study [17]	Half squat	0.74	0.65	0.57	0.50	0.43	0.36	0.29
N = 70 from three studies [18, 24, 25]	Deadlift	1.04	0.93	0.81	0.69	0.57	0.45	0.32
N = 102 from one study [26]	Hip Thrust	0.89	0.79	0.68	0.58	0.48	0.38	0.28
N = 267 from four studies [19, 30–32]	Bench press	1.06	0.89	0.74	0.59	0.45	0.31	0.18
N = 123 from three studies [20, 30, 33]	Prone bench pull	1.31	1.15	1.01	0.87	0.74	0.62	0.50
N = 60 from two studies [36, 37]	Military press	1.16	0.99	0.83	0.67	0.50	0.35	0.19
N = 134 from two studies [21, 38]	Prone pull-up	1.28	1.10	0.93	0.76	0.58	0.41	0.24

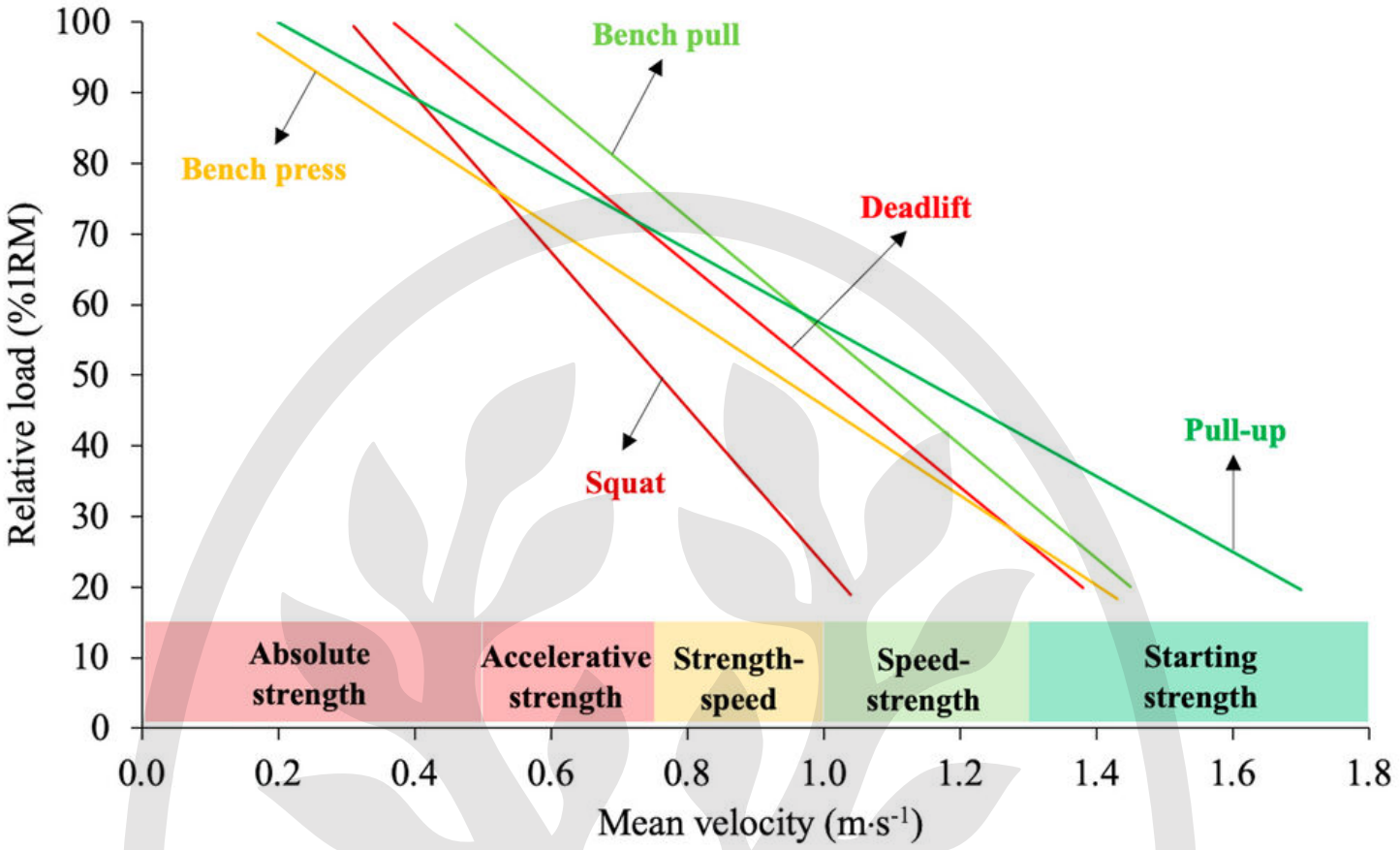
1RM, one-repetition maximum.

Table 2. Analysis of the three commonly used approaches to establish the individual relationship between the relative load (%1RM) and lifting velocity.

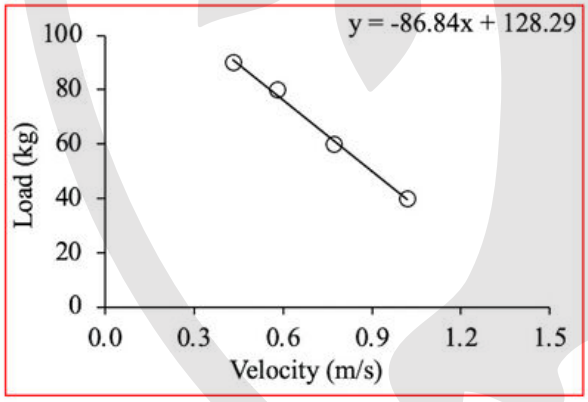
2-sessions with direct 1RM assessment [63]	**1-session with direct 1RM assessment** [10]	**1-session without direct 1RM assessment** [39]
Testing procedure		
1. A full incremental loading test is performed in session 1 to directly assess the 1RM. 2. In session 2, generally performed after 48-h rest, athletes complete repetitions with 20%, 40%, 60%, 80%, and 90% of the 1RM determined in session 1. 3. The fastest MV attained with each relative load (%1RM) is recorded. 4. A linear regression model is applied to establish the individualized %1RM-MV relationship.	1. A full incremental loading test is performed to directly assess the 1RM. 2. The fastest MV attained with each absolute load (kg) is recorded. 3. The absolute loads (kg) are expressed as relative loads (%1RM) based on the directly measured 1RM. 4. A linear regression model is applied to establish the individualized %1RM-MV relationship.	1. An incremental loading test is performed until the MV differs by less than 0.30 $m \cdot s^{-1}$ from the MVT. 2. The fastest MV attained with each absolute load (kg) is recorded. 3. A linear regression model is applied to establish the relationship between the load lifted (kg) and MV, and the 1RM is estimated as the load corresponding to the MVT. 4. The absolute loads (kg) are expressed as relative loads (%1RM) based on the predicted 1RM. 5. A linear regression model is applied to establish the individualized %1RM-MV relationship.
Considerations		
The need of a maximal 1RM test limits its practicability. The accuracy of the individualized %1RM-MV relationship may be compromised if there are differences in the 1RM between both testing sessions.	The need of a maximal 1RM test limits its practicability. It is likely to provide the most accurate individualized %1RM-MV relationship.	It represents the most practical procedure as it does not require a maximal lift. The estimation of the 1RM can introduce some noise in the determination of the individualized %1RM-MV relationship.

1RM, one-repetition maximum; MV, mean velocity; MVT, minimal velocity threshold.





Mean velocity (m/s)	1.02	0.77	0.58	0.43
Load (kg)	40.0	60.0	80.0	90.0
Relative load (%1RM)	35.2	52.9	70.5	79.3



Slope (kg•s/m)	-86.84
Load intercept (kg)	128.29
MVT (m/s)	0.17
Predicted 1RM (kg)	113.5

Cells to modify

Relative load (%1RM)	Mean velocity (m/s)
20%1RM	1.21
25%1RM	1.15
30%1RM	1.08
35%1RM	1.02
40%1RM	0.95
45%1RM	0.89
50%1RM	0.82
55%1RM	0.76
60%1RM	0.69
65%1RM	0.63
70%1RM	0.56
75%1RM	0.50
80%1RM	0.43
85%1RM	0.37
90%1RM	0.30
95%1RM	0.24
100%1RM	0.17

Slope (m/%1RM•s)	-0.013
Velocity intercept (m/s)	1.473