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Update

Determination and control of resistance training intensity and volume in exercise science research and its application

Determinação e controle da intensidade e volume do treinamento de força na pesquisa nas ciências do exercício e sua aplicação

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ABSTRACT
In early studies, where the positive effects of resistance training and repeated muscular efforts were documented, the purpose of science to know the best way to define, control, and dose strength training has been one of the issues that have concentrated the greatest interest and effort. This issue is extremely important since the results that originate from the highest quality scientific works should make it possible to continue generating the body of knowledge that helps to improve the training methodology and, therefore, the participation in the practice of the professionals. For this to be accomplished, scientific studies must have, among other attributes, a precise method for determining and controlling the variables that define the proposed training stimulus to verify the relationship between it and the effects produced. However, if this does not happen, the researchers and training professionals themselves run the risk of making decisions about the configuration of the stimuli (manipulating the variables of the load) based on "false" scientific conclusions, or in the best of cases, uncertain.

Keywords: variables; dosage; quantification; load; intensity; volume.

RESUMO
Nos estudos iniciais, que documentaram os efeitos positivos do treinamento com pesos e a execução de esforços musculares repetidos, o propósito da ciência de conhecer a melhor maneira de definir, controlar e dosar o treinamento de força tem sido uma das questões que concentraram o maior interesse e esforço. Trata-se de uma questão extremamente importante, pois os resultados originários dos trabalhos científicos de maior qualidade devem possibilitar a continuação da geração do corpo de conhecimento que ajuda a melhorar a metodologia do treinamento e, portanto, as participações na prática dos profissionais. Para que isso seja cumprido, os estudos científicos devem ter, entre outros atributos, um método preciso de determinação e controle das variáveis que definem o estímulo do treinamento proposto, a fim de verificar a relação entre ele e os efeitos produzidos. No entanto, se isso não acontecer, pesquisadores e profissionais do treinamento correm o risco de tomar decisões sobre a configuração dos estímulos (manipulação das variáveis da carga) com base em conclusões científicas "falsas" ou incertas, na melhor das hipóteses.

Palavras-chave: variáveis, dosagem, quantificação, carga, intensidade, volume.

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Introduction

Strength training has been used for decades to improve practitioners' athletic performance, health, and quality of life. However, designing a strength training program is not an easy task. Many factors interfere with the training stimulus. It is necessary to know the training principles, such as adaptation, progressive overload, and biological individuality, since they govern training safety and effectiveness [1,2].

The strength training stimulus configuration depends on manipulating several variables that interact with each other, such as the type and order of the exercises, the load magnitude, the number of repetitions and sets, the rest duration between reps, sets, and exercises [1,4]. These variables or indicators manipulation will have different repercussions on the type and magnitude of the physiological response and, consequently, the adaptive response elicited by resistance training [1,2].

In this article, we proposed a critical review of how scientific research and sports practice have traditionally determined, controlled, and programmed intensity and volume, two fundamental and constituent intervention variables (or independent variables) of the "training load". We will also present alternatives that seem to enjoy a higher degree of precision and validity for this objective in the light of new evidence.

The definition, control, and determination of intensity in strength training

The scientific literature identifies the intensity of strength training concerning specific indicators. We will analyze next those considered "gold standards", analyzing their validity, usefulness, and applicability.

Training intensity as a percentage of one-repetition maximum (%1RM)

Traditionally the value of the maximum repetition (1RM), individually valued directly or indirectly estimated, is usually expressed in kilograms (kg), and the definition of intensity, taking the RM as a reference, is carried out based on the percentages of said MR previously obtained [1,4].

In this sense, this way of determining and dosing the relative intensity has certain disadvantages that limit its applicability to the daily practice of training, such as [5,6]: 1) direct assessment of 1RM is time-consuming and may be associated with injury when performed incorrectly or by novice subjects, as well as being impractical for large groups of athletes; 2) the 1RM value is complex to measure, and the value obtained is usually imprecise, that is, it is not real. This situation implies that each absolute load used as a reference RM considered non-real will always represent a different percentage from the programmed one. Only if the 1RM velocity is measured could one be sure that the value obtained could be more accurate [7]; 3) the high variability or oscillation of the current 1RM value over time. This variability would imply the need to constantly carry out evaluations in each exercise to readjust the absolute load calculation corresponding to the relative load programmed according to the capacity of the subject's current performance.

Training intensity as the maximum number of possible repetitions (Nº RM or XRM)

The maximum number of repetitions possible to perform in a set with a submaximal absolute load (for example, 6RM, 10RM) has been suggested as a procedure to define, program, and dose the intensity and even estimate the value of the 1RM through validated regression equations for specific exercises [9–11]. These procedures are proposed assuming an approximate average number of maximum repetitions per set that can be performed with each 1RM percentage according to the exercise type and the training level of the subject [9,10,12], and, therefore, a certain number of maximum repetitions is considered to be representative of a specific relative intensity (%1RM). While this approach eliminates the need for a direct 1RM test, it is not without its drawbacks:

1. Performing repetitions to muscle failure (XRM) is unnecessary for training, which could be counterproductive for improving actions performed at high velocity [13-17].
2. Performing an equal number of maximum repetitions with a given absolute load does not represent, in all cases, the same relative intensity between different subjects since not all of them can perform the same XRM at the same relative intensity [18]. Therefore, if a unique XRM is programmed for a group of subjects, many of them could be training with a different relative intensity, given the high interindividual variability of the XRM performed at the same %1RM [19]. Thus, several studies have reported coefficients of variation from ~ 20 to ~ 50% for the maximum number of repetitions possible to perform under different relative loads (50-90% 1RM) [9,10,18,20-22].
3. In addition to the above, after performing the first set until muscle failure with a specific absolute load, the repetitions number in the following set will inevitably be reduced regardless of the recovery time [23]. However, in numerous studies and scientific documents [1,4,24], the real possibility of performing several consecutive sets with relative intensities, the same absolute load, a number of repetitions per set, and inter-set recovery times is practically impossible to comply with in practice, for example, 3 x 8-12 (70-85% 1RM) / 1-2 min.

Training intensity as the execution velocity in the concentric action (MPV of the 1st repetition)

Currently, because of advances in technology that allow the execution velocity measurement in exercises with free weights, there is the possibility of determining/estimating, with a high degree of precision, the relative intensity (%1RM) that represents the absolute load lifted from the first (or fastest) repetition of the set, always performed at the maximum possible velocity [5,25-28], all this through specific regression equations for each exercise. This result occurs because the mean propulsive velocity of the fastest repetition of the set is intrinsically associated with the relative load magnitude (%1RM), and therefore each %1RM has its velocity [5]. In addition, the execution velocity associated with each %1RM is different and specific to each exercise because the 1RM velocity is different for each exercise [5,7]. These findings are highly relevant for exercise professionals, not only for solving the existing problems to control and dose training intensity in real-time and with high precision, but also for allowing the study and knowledge of the true dose-response relationship of the training carried out, for the first time.

Therefore, velocity in concentric action is an objective and reliable indicator of strength training intensity and, whenever possible, it should be adequately controlled in any strength training (rather than using %1RM or an XRM) [5,6]. To be fulfilled, the only condition is that the load always moves at the maximum possible velocity in the concentric phase [5].

At this point, it is necessary not only to have analyzed how intensity should be controlled, programmed, and determined but also to propose an unequivocal definition of it for strength training. In this regard, we would say that intensity will be represented by the "degree of effort involved in performing the first repetition of the set, performed at the maximum possible velocity" [5,6]. Based on this intensity definition applied to strength training, it is essential to record the need not to confuse "intensity" with the degree of effort or fatigue involved in performing all the repetitions programmed for the set. For example, there is no doubt that performing 3 x 10 (70% 1RM) represents a degree of effort greater than 3 x 5 (70% 1RM); however, the intensity used would be the same in both cases (70%).

Training intensity as repetitions in reserve (RIR)?

Some publications have suggested using the value of the "repetitions in reserve" (RIR), understood as the number of repetitions that remain unperformed in a set to failure [29,30], as an indicator of strength training intensity. Although this value is of interest in the research field and valuable to adjust the load, it is no less accurate that this has been misinterpreted at the time of application by professionals since it has been proposed as an alternative for load definition and intensity.

This interpretation would not be possible, mainly because defining a stimulus by performing repetitions in reserve (RIR) would not allow having the information on the stimuli characteristics to be applied. For example, we could program an

RIR of (-2) for a particular exercise in each set. However, this numerical value does not allow us to know the applied stimulus unless complemented by the number of possible repetitions with the said absolute load. The RIR results from the difference between the repetitions completed and the maximum achievable in the set (defined later as "level of effort"), but it cannot be used or applied by itself to determine the training stimulus.

The quantification, control, and dosage of volume in strength training

The scientific literature identifies the volume of strength training concerning specific indicators. We will analyze the validity, usefulness, and applicability of these indicators considered as "gold standards".

Training volume as the total number of performed repetitions

In most of the literature on strength training, the traditional and basic way to quantify and express volume is through the total number of repetitions performed in a given exercise, a training session, or any temporal structure of the programming (week, month, cycle, so on), and the total of repetitions of a training session is dependent on the number of exercises, sets and the repetitions per set [1,4,31]. In this way, the usual thing in scientific studies (and training programs) is to prescribe the volume of each set through a pre-established number of repetitions for all the subjects of a group who train with a certain relative intensity.

Likewise, from this simple volume quantification procedure, numerous studies have proposed multiplying the total number of repetitions (sets x repetitions) by the absolute load (kg) used in each exercise [32-34], obtaining an absolute value of kilograms or tonnage (for example, 3 x 10 x 50 kg = 1500 kg). However, it does not make sense to compare measurements of absolute volumetric load (kg, tonnage) between individuals and different exercises since this measurement does not reflect the degree of effort that this volume represents either. Faced with these types of limitations, other authors have proposed considering the total number of repetitions performed concerning the individual relative intensity (%1RM) to obtain a more individualized parameter of the effort that represents the volume performed (relative volume = sets x repetitions x %1RM) [33]. By linking the volume (sets x repetitions) with the percentage of the 1RM, a value is obtained in arbitrary units that express the impact of the training with greater precision and allows comparisons between different individuals [4]. However, this procedure could also provide identical volumes but representing totally different stimuli (for example, 3 x 10 x 70% would be the same relative volume value as 10 x 3 x 70%).

The truth is that all these traditional approaches to volume expression and quantification assume that when a group of subjects performs the same number of repetitions per set of an exercise and with the same relative intensity, the programmed degree of effort and the associated real effort are equivalent to each other.

However, this might not be the case, since if during a session all the subjects performed the same number of repetitions per set at the same specific relative load (%1RM), it is very likely that many of them were a different level of effort or fatigue, as has been commented. If we assume this situation, in all those studies in which training volume has been controlled and dosed for a predetermined number of repetitions per set that is the same for all participants, the degree of fatigue generated or the degree of effort exerted could have been different for a large part of the participants. Then, the question remaining is: How could this problem have influenced the results of the studies and the conclusions derived from them?

In either case, the training volume will always have little or no value if it is not accompanied by the intensity variable, correctly determined, and controlled [6]. In other words, the training volume cannot be a component of the load that by itself characterizes or precisely defines the type of stimulus used.

Velocity loss in the set (%VL) as a control and dosage procedure of the training volume

The training volume should be defined, controlled, and dosed more concretely and objectively by the relative velocity loss achieved in the set (expressed as the percentage difference between the velocity of the fastest repetition - the first - and the slowest - the last - of the set) [19], and only failing that by the total number of repetitions carried out (assuming the previously mentioned inconveniences or limitations). For the same velocity loss in the set, this procedure allows a similar degree of effort or fatigue to be achieved among subjects who perform a training protocol with the same relative intensity. However, if these subjects perform a different number of repetitions [19], the relative velocity loss equalizes the effort throughout a set and not the number of repetitions performed with the same relative load [19]. This result occurs because, if the effort is maximum in its concentric action, the decline in execution velocity during a set of repetitions is directly proportional to the increase in neuromuscular fatigue [6,35].

Therefore, instead of programming and performing a fixed or predetermined number of repetitions, the most suitable alternative to setting the training volume should be to stop or end each set as soon as a certain magnitude or percentage of velocity loss is reached in the set, depending on the objective [12,16,19,36].

Training volume as time under tension (TUT)?

The training volume is directly related to the duration or the magnitude of the stimulus time. For this reason, in some studies, training volume was associated with the time “under tension” when performing an exercise [37]. However, the time required to complete a set depends on different factors, such as, for example, the number of repetitions, the movement velocity for each repetition in the concentric phase, the movement velocity for each repetition in the eccentric phase, the transition time between concentric and eccentric phase, the time interval between repetitions, relative load, and others. All these determinants of time under tension are challenging to control, interacting with each other, and therefore cannot express a value that objectively represents the resistance training volume.

In the same way, it is not possible to prescribe an established execution time per repetition (for example, 2: 0: 2) and that this is maintained throughout a maximum number of maximum repetitions when raising volumes that approach muscle failure.

Definition and control of the strength training stimulus magnitude, or training load

In the previous sections, we have delved into the need to review and update how intensity and volume variables are individually defined and controlled in strength training. However, for the same exercise, the magnitude of the training load would be determined by the interaction of both variables (volume and intensity), and through it, the degree of "global" effort that the training stimulus represents can be defined and accurately assessed [6].

The training load as the level of effort (LE)

In strength training, the "level of effort" (LE) is the factor that expresses the relationship between the effort made and the achievable or possible that the subject can manifest at all times [37] and, therefore, it will be determined by the relationship between the number of repetitions performed per set concerning the maximum possible to perform in the same exercise, with the same weight and at the same time [12,38]. The training load through this factor is expressed and programmed, indicating the number of repetitions per set to be performed (which represents the volume) and, in parentheses, the maximum number of repetitions that the subject could achieve with the indicated weight (which represents relative intensity).

Therefore, the LE relates to and defines the training stimulus/load magnitude but should not confuse the training intensity itself. The LE can be an efficient procedure, accessible to all professionals, and applicable to most exercises. Its main advantage, apart from the immediacy of its programming without the need to carry out any test, is that the effort made will be more precisely adjusted to the programmed effort, and therefore it will be able to express the degree of effort made by the subject in each of the exercises. It should be noted that the application of this methodology requires a careful educational process and involvement on the part of the coach and athlete [37].

The effort index (EI) as a value of the training load magnitude of each exercise

From all the above, it can be deduced that the degree of effort definition and quantification during strength training is expressed and determined through the relationship between intensity and volume itself. By controlling the execution velocity, we can assess very precisely the degree of effort or degree of fatigue that a subject has experienced during training through the velocity of the first repetition (which can be used to determine the relative intensity) and the percentage of velocity loss in the set (which may be used to determine the volume). Both variables significantly influence the degree of stress induced by the strength training [6,12,16]. These same advances have allowed the emergence of a highly valid numerical indicator that represents, predicts, and quantifies the degree of effort or fatigue that a set or several sets have meant, called the "effort index" (EI), and which is specific for each exercise [39]. This index is defined by the product of the first (fastest) repetition velocity and the value of the relative velocity loss in the set. It is closely related to indicators of metabolic stress (r = 0.95 and 0.90 for bench press and squat, respectively) and mechanical fatigue variables, such as the relative velocity loss pre-post effort with the load that can be displaced at 1 m/s (r = 0.98 and 0.91 for bench press and squat, respectively) and height loss in CMJ (r = 0.93) [39]. In this way, the same load magnitude (index or degree of effort) can be obtained by combining different values of intensity (velocity of the first repetition) and volume (% velocity loss within a set).

With this new numerical indicator, it has also been found that the same value or result induces and represents an equivalent degree of fatigue, independently of the velocity of the first repetition and the intra-set velocity loss, at least for relative intensities ranging from 50 to 80% 1RM [39].

EI = 1st rep MPV x %VL

MPV = mean propulsive velocity of the 1st repetition of the set
%VL = percentage of velocity loss in the set

Thus, it is easy to understand that low or moderate-intensity (45-70% 1RM, that is, medium or high velocities), in combination with an increased number of repetitions per set (12 to 15 or more, that is, a high-velocity loss) may lead to a high "effort index" (degree of fatigue) (Table I). What would then need to recommend or prescribe loads of the 3x12-15RM type in programs aimed at sedentary, untrained, or with specific pathologies people?

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Table I - Effort index of intensities between 40 and 95% with different velocity losses (10 to 55%) in the full squat exercise

Relative intensity	Set mean propulsive velocity loss (%)									
%1RM (VMP m/s)	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%
40% (~1.28 m/s)	12.8	19.2	25.5	31.8	38.1	44.5	50.8	57.1	63.5	69.8
45% (~1.20 m/s)	12.1	18.1	24.1	30.0	36.0	42.0	47.9	53.9	59.9	65.9
50% (~1.13 m/s)	11.4	17.0	22.6	28.3	33.9	39.5	45.1	50.7	56.3	61.9
55% (~1.06 m/s)	10.7	15.9	21.1	26.5	31.7	37.0	42.2	47.5	52.8	58.0
60% (~0.98 m/s)	10.0	14.9	19.8	24.7	29.6	34.5	39.4	44.3	49.2	54.1
65% (~0.90 m/s)	9.3	13.8	18.4	22.9	27.4	32.0	36.5	41.1	45.6	50.2
70% (~0.83 m/s)	8.5	12.7	16.9	21.1	25.3	29.5	33.7	37.9	42.1	46.3
75% (~0.75 m/s)	7.8	11.7	15.5	19.3	23.2	27.0	30.8	34.7	38.5	42.4
80% (~0.68 m/s)	7.1	10.6	14.1	17.5	21.0	24.5	28.0	31.5	35.0	38.4
85% (~0.60 m/s)	6.4	9.5	12.6	15.8	18.9	22.0	25.1	28.3	31.4	34.5
90% (~0.52 m/s)	5.7	8.4	11.2	14.0	16.7	19.5	22.3	25.1	27.8	30.6
95% (~0.44 m/s)	4.9	7.4	9.8	12.2	14.6	17.0	19.4	21.9	24.3	26.7

It can be seen how a low training intensity (for example, 45%) always supposes an effort index more significant than a moderate intensity (for example, 70%) for the same velocity loss [39].

Conclusions for practice and research in exercise science

For the same exercise, intensity and volume are the most determining variables of the strength training effect [1,40]. Therefore, its determination and control must be carried out using an accurate and validated methodology. However, the traditional determination and dosage of intensity using 1RM percentages present impediments that limit its applicability to daily practice, such as, for example, the high variability of the 1RM value on a day-to-day basis. In turn, any study or training protocol that establishes the determination of intensity through a maximum number of repetitions will be incurring with high probability in providing a different relative intensity for each subject, in addition to generating a degree of fatigue that is undoubtedly unnecessary and counterproductive. On the other hand, the control and dosage of the training volume through the same number of repetitions per set before a certain intensity is a procedure where the degree of effort or resulting fatigue (velocity loss in the set) will be unequal for each of the trained subjects. Therefore, these traditional procedures to control both variables are not appropriate or rational for neither scientific research nor sports practice. However, when there are no resources or the time required to control and adjust the training load objectively, using the "level of effort" based on the number of repetitions will be a sufficiently precise and adequate alternative practice.

This panorama should make us reflect on whether the knowledge acquired about strength training from scientific studies where volume and intensity have not been adequately controlled can be sufficiently valid and applicable. In our opinion, we may have to "redo" part of the path we have traveled in this field to advance research and training methodology in the future firmly. For this reason, research in exercise science should consider using execution velocity as a reference for the dosage and control of the training load and the effect it produces, which would also allow the comparison between the scheduled training program and that actually performed in studies.

Potential conflict of interest
No potential conflicts of interest relevant to this article have been reported.

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