Velocity Loss as a Variable for Monitoring Resistance Exercise

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ABSTRACT

This study aimed to analyze: 1) the pattern of repetition velocity decline during a single set to failure against different submaximal loads (50–85 % 1RM) in the bench press exercise; and 2) the reliability of the percentage of performed repetitions, with respect to the maximum possible number that can be completed, when different magnitudes of velocity loss have been reached within each set. Twenty-two men performed 8 tests of maximum number of repetitions (MNR) against loads of 50–55–60–65–70–75–80–85 % 1RM, in random order, every 6–7 days. Another 28 men performed 2 separate MNR tests against 60 % 1RM. A very close relationship was found between the relative loss of velocity in a set and the percentage of performed repetitions. This relationship was very similar for all loads, but particularly for 50–70 % 1RM, even though the number of repetitions completed at each load was significantly different. Moreover, the percentage of performed repetitions for a given velocity loss showed a high absolute reliability. Equations to predict the percentage of performed repetitions from relative velocity loss are provided. By monitoring repetition velocity and using these equations, one can estimate, with considerable precision, how many repetitions are left in reserve in a bench press exercise set.

Introduction

Resistance training (RT) is recognized as an effective method for improving athletic performance because it typically results in increases in muscle strength and hypertrophy, power output, speed, and local muscular endurance [16]. However, one of the main problems faced by coaches, strength and conditioning professionals and researchers is the issue of how to objectively quantify and monitor the actual training load undertaken by athletes in order to maximize performance [11]. Although several acute variables have been described for the design of RT programs [3, 16], it appears that exercise intensity and volume are the two most critical factors in determining the type and extent of the resulting neuromuscular adaptations [3, 7, 8, 27].

Exercise intensity during RT has been traditionally identified with relative load (percentage of one-repetition maximum, %1RM) or with the maximal load that can be lifted a given number of repetitions in each set (e. g., 5RM, 10RM, 15 RM) [7, 8, 11, 16]. However, these methods appear to have some potential disadvantages [8, 11]. As an alternative, recent research has examined the possibility of using movement velocity as an indicator of relative load during resistance exercise [11, 17, 19, 23, 24]. Close relationships between movement velocity and %1RM have been found for exercises such as the bench press (BP), prone bench pull and squat [11, 17, 24], which makes it possible to determine with considerable precision the %1RM that is being used as soon as the first repetition of a set is performed with maximal voluntary velocity [11]. Such findings open up the possibility of monitoring, in real time, the actual load (%1RM) being used by measuring repetition velocity during RT, thus allowing to determine whether the proposed load (kg) truly represents the %1RM that was intended for each session.

On the other hand, training volume is generally determined from the total number of sets and repetitions performed during a training session [3, 13, 16]. Thus, when training volume is prescribed, the vast majority of studies use a specific number of repetitions to complete in each exercise set for all participants. However, the maximal number of repetitions that can be completed against a given relative load has been found to present a large variability between individuals [22, 26, 28]. Therefore, if during a training session all participants perform the same number of repetitions per set against the same relative load (e. g., 70 % 1RM), it is possible that they are exerting a different level of effort (i. e., the number of repetitions left in reserve in each set may vary considerably between individuals). These considerations suggest it is necessary to find better ways to objectively monitor training volume during RT. Accordingly, rather than performing a fixed, predetermined, number of repetitions, it seems more appropriate to stop or terminate each training set as soon as a certain level of neuromuscular fatigue is detected (which, in turn, will depend on the specific goal being pursued) [19, 23]. During RT in isoinertial conditions, and assuming every repetition is performed with maximal voluntary effort, an unintentional decrease in force, velocity and hence power output is observed as fatigue develops and the number of repetitions approaches failure [15, 19, 23]. Recent research has shown that monitoring repetition velocity is an objective, practical and non-invasive indicator of the acute metabolic stress, hormonal response and mechanical fatigue induced by RT [10, 18–20, 23]. Repetition velocity has shown a very similar pattern of decrease during a single set to failure for loads ranging from 60 % to 75 % [15]. However, to our knowledge, the question of how many repetitions remain undone (left in reserve) in an exercise set when a given magnitude of velocity loss is reached (e. g., 20, 30 or 40 % reduction in repetition velocity) has not yet been investigated.

Therefore, in the context of a velocity-based resistance training approach [19, 23], two separate studies were undertaken. The main purpose of *Study I* was to analyze and compare the pattern of repetition velocity decline during a single set to failure in the BP exercise against 8 different submaximal loads (50, 55, 60, 65, 70, 75, 80 and 85 % 1RM). *Study II* was a complementary study that aimed to analyze the reliability of the percentage of performed repetitions with respect to the maximum, to failure, number that can be completed for different magnitudes of velocity loss within a set to failure against a load of 60 % 1RM in the BP.

Methods

Participants

A group of 22 (mean ± SD: age 24.6 ± 3.6 years; height 1.76 ± 0.06 m; body mass 75.8 ± 7.2 kg) young healthy men volunteered to participate in *Study I*. Their estimated one-repetition maximum ($1RM_{est}$) in the BP exercise was 80.5 ± 10.8 kg (1.05 ± 0.11 normalized per kg of body mass). An additional group of 28 men (24.5 ± 2.9 years, 1.77 ± 0.07 m, 75.5 ± 8.1 kg) participated in *Study II*. In this case, their $1RM_{est}$ was 82.6 ± 13.8 kg (1.07 ± 0.20 normalized per kg of body mass). All participants were physically active sport science students with at least 8 months of recreational RT experience in the BP exercise. No physical limitations, health problems or musculoskeletal injuries that could affect testing were reported. None of the participants were taking drugs, medications or substances expected to affect physical performance or hormonal balance. The present investigation met the ethical standards of this journal [12] and was approved by the Research Ethics Committee of Pablo de Olavide University. After being informed of the purpose and experimental procedures, the participants signed a written informed consent form prior to participation.

Study design

Familiarization and preliminary measures

In the preceding 2 weeks of each study (I and II), four preliminary familiarization sessions were undertaken for the purpose of emphasizing proper execution technique in the BP exercise. Several practice sets with different loads, with each repetition performed at maximal intended velocity, were carried out while receiving immediate velocity feedback from the measuring system and verbal cues from a trained researcher. In the last familiarization session, individual load-velocity relationships and $1RM_{est}$ strength in the BP exercise were determined using a progressive loading test (described later in detail). Anthropometric assessments and medical examinations were also conducted during these sessions. Height and body mass were determined using a medical stadiometer and scale (Seca 710, Seca Ltd., Hamburg, Germany) with the participants in a morning fasting state and wearing only underclothes. Arm length was measured while the participants were standing upright, with feet shoulder-width apart, and arms and fingers outstretched. The measurement was made on the right side from the lateral edge of the acromion to the tip of the middle finger using an inextensible measuring tape (Lufkin Ultralok, Baltimore, Maryland, USA).

Study I

A cross-sectional research design was used to analyze the magnitude of percent velocity loss incurred during a single set to failure against 8 different submaximal loads (50 , 55 , 60, 65, 70, 75 , 80 and 85 % 1RM) in the BP exercise. These 8 sessions were performed on different days, in random order for each participant, and were separated by a time period of 6–7 days. During each session, participants performed a test of maximum number of repetitions to failure (MNR test) against the corresponding load. Relative loads were determined from the load-velocity relationship for the BP because it has been shown that there is a very close relationship between %1RM and mean propulsive velocity (MPV) for this exercise [11, 24]. Thus, a target MPV to be attained in the first (usually the fastest) repetition of the set in each session was used as an estimation of %1RM, as follows: ~0.93 $m \cdot s^{-1}$ (50 % 1RM), ~0.86 $m \cdot s^{-1}$ (55 % 1RM), ~0.79 $m \cdot s^{-1}$ (60 % 1RM), ~0.71 $m \cdot s^{-1}$ (65 % 1RM), ~0.62 $m \cdot s^{-1}$ (70 % 1RM), ~0.54 $m \cdot s^{-1}$ (75 % 1RM), ~0.47 $m \cdot s^{-1}$ 80 % 1RM), and ~0.39 $m \cdot s^{-1}$ (85 % 1RM) [9, 11]. The absolute load (kg) for each participant was individually adjusted to match the velocity associated (± 0.02 $m \cdot s^{-1}$) with the %1RM intended for each session.

Study II

Participants performed an MNR test against a 60 % 1RM load (~0.79 $m \cdot s^{-1}$) on 2 different sessions, separated by 6–7 days.

For both studies, sessions were performed at the same time of day (± 1 h) for each participant and under similar environmental conditions (~20–22 °C and ~55–65 % humidity). In addition, participants were required to refrain from any type of RT during the 2 days preceding each session. The same standardized warm-up protocol was strictly followed by all participants for all testing sessions. This warm-up consisted of 5 min of joint mobilization and gentle stretching exercises, followed by 3 to 4 sets with progressive loads (3 min rests) up to the corresponding target load.

Testing procedures

Isoinertial progressive loading test in the BP exercise

Testing was performed using a Smith machine. Participants laid supine on a flat bench, with their feet resting flat on the floor and hands placed on the bar slightly wider (2–3 cm) than shoulder width. The position on the bench was carefully adjusted so that the vertical projection of the bar corresponded with each participant's intermammary line. The individual position on the bench as well as grip widths were measured so that they could be reproduced on every lift. Participants were not allowed to bounce the bar off their chests or raise the shoulders or trunk off the bench. Two telescopic bar holders with a precision scale were placed at the left and right sides of the Smith machine in order to: (i) precisely replicate the individual eccentric range of movement between trials; and (ii) impose a pause or delay between the eccentric and concentric phases of the BP exercise. The bar holders were positioned so that the bar stopped ~1 cm above each participant's chest. After lowering the bar at a controlled mean eccentric velocity (~0.30–0.50 $m \cdot s^{-1}$), participants stopped for ~1.5 s at the bar holders (momentarily releasing the weight but keeping contact with the bar), and thereafter they performed a purely concentric push at maximal intended velocity. This momentary pause between phases was imposed in order to minimize the contribution of the rebound effect and allow for more reliable, consistent measures [17]. Each participant was carefully instructed to always perform the concentric phase of each repetition in an explosive manner, exploding the bar off the chest as fast as possible upon hearing the 'go!' command from a researcher. Warm-up consisted of 5 min of joint mobilization exercises, followed by 2 sets of 8 and 6 repetitions (3 min rest) with loads of 20 and 30 kg, respectively. The initial load was set at 20 kg for all participants and was gradually increased in 10 kg increments. The test ended for each participant when the attained concentric MPV was lower than 0.35 $m \cdot s^{-1}$, which corresponds to ~88 % 1RM [11, 24]. During the test, 3 repetitions were executed for light (MPV > 0.95 $m \cdot s^{-1}$), 2 for medium (0.95 $m \cdot s^{-1}$ > MPV > 0.55 $m \cdot s^{-1}$), and only one for the heaviest (MPV < 0.55 $m \cdot s^{-1}$) loads. Inter-set rests ranged from 2 (light loads) to 4 min (heavy loads). The $1RM_{est}$ was calculated for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading test, as follows: $(100 \cdot load)/(8.4326 \cdot MPV^2) - (73.501 \cdot MPV) + 112.33$ [11].

Tests of maximum number of repetitions to failure

Before starting each set to failure (50–85 % 1RM, in 5 % increments), adjustments in the load (kg) to be used were made when needed so that the velocity of the first repetition matched the specified target MPV corresponding to each load (see the above description of *Study I*). During each test, the participants were required to move the bar as fast as possible during the concentric phase of each repetition, until reaching muscle failure. As done for the isoinertial progressive loading test, participants were required to perform the eccentric phase of each repetition in a controlled manner, stop at the bar holders for ~1.5 s, and then explode the bar off the chest as fast as possible upon hearing a command.

Measurement equipment and data acquisition

A Smith machine (Multipower Fitness Line, Peroga, Spain) that ensures a smooth vertical displacement of the bar along a fixed pathway was used for all sessions. A cable-extension linear velocity transducer (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) was used to measure bar velocity. Instantaneous velocity was sampled at 1000 Hz and smoothed using a 4th order low-pass Butterworth filter with no phase shift and 10 Hz cutoff frequency. The system's software automatically calculated the relevant kinematics of every repetition, provided auditory and visual velocity feedback in real time and stored data on disk for analysis. The reliability of this system has been reported elsewhere [23].

Velocity measures

Several velocity outcome measures were used as performance variables in this study: 1) mean propulsive velocity (MPV): average of the bar velocity values of the propulsive phase, defined as that portion of the concentric action during which the measured acceleration (a) is greater than acceleration due to gravity, i. e., a ≥ –9.81 $m \cdot s^{-2}$ [25]; 2) MPV of the fastest (usually first) repetition in the set (MPV_{BEST}); 3) MPV of the last repetition in the set (MPV_{LAST}); and 4) MPV loss over each exercise set, defined as: $100 \cdot (MPV_{LAST} - MPV_{BEST})/MPV_{BEST}$.

Statistical analysis

Standard statistical methods were used for the calculation of mean, standard deviation (SD), coefficient of variation (CV) and Pearson's correlation coefficients (r). Significance was accepted at $P \leq 0.05$. All analyses were performed using SPSS software version 17.0 (SPSS, Chicago, IL).

Study I

The Shapiro-Wilk test was applied to determine the nature of the data distribution. Differences in the variables analyzed between the 8 loading magnitudes used (50–85 %, in 5 % increments) were assessed using a one-way ANOVA with repeated-measures. Bonferroni post hoc procedures were performed to locate the pairwise differences between the means. Relationships between variables were studied by fitting 2nd order polynomials to the data.

Study II

A paired t-test was used to detect differences in the percentage of completed repetitions with respect to the maximum possible number between the 2 MNR tests at 60 % 1RM for each percentage of velocity loss incurred in the set. Absolute reliability was reported for the percentage of repetitions completed at each percentage of velocity loss using the standard error of measurement (SEM). The SEM values were expressed as a percentage of their respective means through the CV [1]. Previous reliability studies [2, 4] have reported biomechanical variables with CVs in the vicinity of 10 % as reliable. As a result, a CV of ≤ 10 % was set as the criterion to declare a variable as reliable.

Results

Study I

▶ **Table 1** summarizes the pattern of repetition velocity decline observed for the set to failure performed against each of the 8 loads under study. No significant differences were found between the expected or targeted MVP values and the fastest MPV values (MPV_{BEST}) of each set for any of the loads used. Average MPVs of the last repetition of each set (MPV_{LAST}) were very similar for all the loads used (▶ **Table 1**). As loading magnitude increased, both the number of performed repetitions ($R^2 = 0.998$) and the magnitude of MPV loss ($R^2 = 0.969$) progressively decreased (▶ **Table 1**; ▶ **Fig. 1**). The number of repetitions performed against each load showed a large inter-individual variability (CV: 17.3–23.5 %; ▶ **Table 2**), and

▶ **Table 1** Study I. Descriptive variables for the exercise sets to failure performed against the 8 loading magnitudes under study.

Load (% 1RM)	MPV_{BEST} ($m \cdot s^{-1}$)	MPV_{LAST} ($m \cdot s^{-1}$)	Velocity loss (%)	Rep	Load (kg)
50% (~0.93 $m \cdot s^{-1}$)	0.93 ± 0.01 (0.91–0.94)	0.14 ± 0.03 (0.09–0.22)	84.7 ± 3.7 [c,d,e,f] (76.1–90.5)	25.7 ± 5.8 [a,b,c,d,e,f] (19–40)	37.7 ± 5.2 [b,c,d,e] (27.5–45.0)
55% (~0.86 $m \cdot s^{-1}$)	0.86 ± 0.01 (0.84–0.88)	0.14 ± 0.04 (0.08–0.22)	83.2 ± 4.6 [d,e,f] (74.4–90.1)	22.7 ± 4.4 [b,c,d,e,f] (16–32)	40.9 ± 7.5 [c,d,e] (29.0–55.0)
60% (~0.79 $m \cdot s^{-1}$)	0.79 ± 0.01 (0.77–0.81)	0.13 ± 0.02 (0.09–0.19)	82.5 ± 3.1 [d,e,f] (76.3–88.1)	19.6 ± 3.4 [c,d,e,f] (15–26)	44.3 ± 6.7 [c,d,e] (30.0–54.0)
65% (~0.71 $m \cdot s^{-1}$)	0.71 ± 0.01 (0.69–0.73)	0.14 ± 0.04 (0.07–0.25)	80.4 ± 5.9 [d,e,f] (66.1–90.1)	16.2 ± 3.4 [d,e,f] (12–22)	46.8 ± 11.9 [d,e] (34.5–61.0)
70% (~0.62 $m \cdot s^{-1}$)	0.62 ± 0.01 (0.60–0.64)	0.13 ± 0.03 (0.06–0.18)	79.2 ± 4.7 [e,f] (70.5–90.3)	12.6 ± 2.7 [e,f] (9–19)	54.1 ± 7.7 [e] (34.5–65.0)
75% (~0.54 $m \cdot s^{-1}$)	0.54 ± 0.01 (0.52–0.56)	0.13 ± 0.02 (0.08–0.19)	75.7 ± 4.4 [f] (65.6–84.0)	9.8 ± 1.7 [f] (7–13)	57.5 ± 13.8 (39.0–72.5)
80% (~0.47 $m \cdot s^{-1}$)	0.47 ± 0.01 (0.45–0.49)	0.12 ± 0.02 (0.08–0.16)	73.6 ± 5.3 [f] (65.9–82.9)	7.7 ± 1.5 (5–10)	63.0 ± 7.6 (44.0–75.0)
85% (~0.39 $m \cdot s^{-1}$)	0.39 ± 0.01 (0.37–0.41)	0.14 ± 0.02 (0.11–0.18)	63.9 ± 5.1 (54.8–73.2)	4.9 ± 1.2 (4–8)	68.3 ± 10.4 (48.0–88.0)

Data are mean ± SD (range)

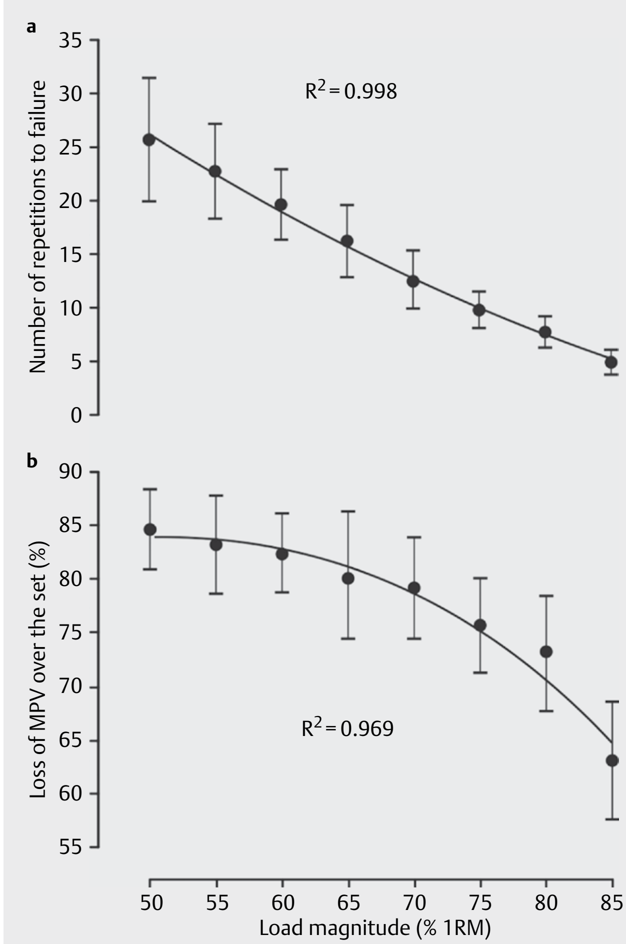
Rep: number of completed repetitions in the set; MPV_{BEST}: mean propulsive velocity of the fastest (usually first) repetition in the set; MPV_{LAST}: mean propulsive velocity of the last repetition in the set

Statistically significant differences with respect to: [a] 60% 1RM; [b] 65% 1RM; [c] 70% 1RM; [d] 75% 1RM; [e] 80% 1RM; [f] 85% 1RM

showed no relationship to either anthropometric (body mass, height, arm length) or mechanical variables (MPV_{BEST}, MPV_{LAST}, loss of MPV over the set, $1RM_{est}$ and $1RM_{est}$/body mass) (▶ **Table 3**).

The percentages of performed repetitions with respect to the maximum possible number that can be completed in each set to failure when a given magnitude of MPV loss (15–75%) is reached were very similar for loads ranging from 50 to 70% 1RM (▶ **Table 4**). However, these percentages of performed repetitions for a given magnitude of MPV loss were progressively greater for 75, 80 and 85% 1RM, respectively (▶ **Fig. 2**). The CV for the percentage of performed repetitions with respect to the maximum possible number that can be completed in each set to failure ranged from 2.7 to 12.1% depending on the loss of MPV reached in the set (▶ **Table 2**).

A prediction equation to estimate the percentage of performed repetitions (% Rep) when a given magnitude of MPV loss is reached in an exercise set for loads of 50–70% 1RM in the BP is provided: % Rep = $-0.00855 \cdot$ MPV loss^2 + $1.83311 \cdot$ MPV loss + 5.55281 ($R^2 = 0.964$; SEE = 5.44%). For 75% 1RM, the resulting equation was: % Rep = $-0.00705 \cdot$ MPV loss^2 + 1.71404 MPV loss + 10.74584 ($R^2 = 0.968$; SEE = 5.15%), whereas for 80% 1RM the equation



▶ **Fig. 1** Study I. Relationship between the load magnitude and: **a** number of performed repetitions to failure; **b** relative loss of MPV over each set to failure in the bench press exercise. See text for details. The vertical error lines represent the standard deviation.

▶ **Table 2** Study I. Coefficient of variation (CV) for: i) number of repetitions performed at each load magnitude; and ii) the percentage of completed repetitions with respect to the maximum possible number when a given percentage of MPV loss is reached in each set to failure against the corresponding relative load.

Load (%1RM)	CV (%) for Rep	CV (%) for each percentage of MPV loss												
		15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%
50% ($\sim 0.93\,m \cdot s^{-1}$)	22.4	11.6	10.1	9.8	9.5	9.1	8.8	8.1	7.3	6.5	5.1	4.2	3.8	3.1
55% ($\sim 0.86\,m \cdot s^{-1}$)	19.5	11.1	10.6	9.9	9.1	8.4	7.9	7.2	6.3	5.5	4.7	3.8	3.1	2.5
60% ($\sim 0.79\,m \cdot s^{-1}$)	16.8	11.4	10.9	9.5	8.5	7.6	6.9	6.3	5.6	5.0	4.5	4.0	3.6	3.0
65% ($\sim 0.71\,m \cdot s^{-1}$)	20.9	8.5	7.5	7.0	6.5	6.1	5.7	5.2	4.6	4.1	3.5	3.1	2.7	2.7
70% ($\sim 0.62\,m \cdot s^{-1}$)	21.5	11.0	10.5	9.7	8.8	8.1	7.4	6.8	6.1	5.4	4.8	4.4	4.1	4.1
75% ($\sim 0.54\,m \cdot s^{-1}$)	17.5	10.9	10.3	9.8	9.2	8.5	7.8	7.1	6.3	5.5	4.7	4.0	3.5	3.5
80% ($\sim 0.47\,m \cdot s^{-1}$)	18.9	11.2	10.8	10.3	9.9	9.1	8.5	7.8	7.0	6.2	5.6	5.0	4.3	4.1
85% ($\sim 0.39\,m \cdot s^{-1}$)	23.5	12.1	11.0	10.1	9.2	8.3	7.4	6.5	5.5	4.6	3.8	3.3		

MPV: mean propulsive velocity; Rep: number of completed repetitions in the set

CV for the percentage of completed repetitions when 70% and 75% of MPV loss are reached against 85% 1RM do not appear in the table because the maximum MPV loss that can be reached in the set against this load is approximately 65%

was: $\%\,Rep = -0.00780 \cdot MPV\,loss^2 + 1.72215\,MPV\,loss + 13.38519$ ($R^2 = 0.965$; SEE = 5.39%). Finally, the resulting equation for 85% 1RM was: $\%\,Rep = -0.00813 \cdot MPV\,loss^2 + 1.74323\,MPV\,loss + 20.88282$ ($R^2 = 0.960$; SEE = 5.75%).

Study II

Descriptive and variability data for the 2 MNR tests performed against 60% 1RM are presented in ▶ **Table 5** and ▶ **Table 6**, respectively. No significant differences were found for any mechanical variable between trials 1 and 2 (▶ **Table 5**). Paired t-tests revealed no significant differences between trials for any percentage of repetitions completed at each magnitude of MPV loss. The percentages of repetitions completed had very high absolute reliability (CV: 2.1–6.6%), with lower CV values as the loss of MPV over the set increased.

Discussion

This study aimed to analyze the pattern of repetition velocity decline during a single set to muscle failure against 8 different loads in the BP exercise. The main finding of *Study I* was that there exists a very close relationship between the relative loss of velocity in a set and the percentage of performed repetitions with respect to the maximum number that can be completed (i.e., proximity to muscle failure) (▶ **Fig. 2**). This is an interesting and practical finding because by monitoring repetition velocity during RT one can estimate, with considerable precision, how many repetitions are left in reserve in a given exercise set (which corresponds to the concept of 'level of effort' [8, 10, 18, 23]). In *Study II* we also found that the percentage of performed repetitions for a given magnitude of MPV loss, against a 60% 1RM load, showed a high absolute reliability (▶ **Table 6**).

The close relationship found between relative loss of repetition velocity and percentage of performed repetitions was very similar for loads between 50–70% 1RM (▶ **Fig. 2a**, ▶ **Table 4**), even though the number of repetitions completed against each of these relative loads was significantly different (▶ **Table 1**). Interestingly, for heavier loads (75%, 80% and 85% 1RM), the percentages of performed repetitions for a given magnitude of MPV loss were slightly higher than those observed against loads of 50–70% 1RM (▶ **Fig. 2**). It is for this reason that 4 different equations (for loads of 50–70% 1RM, 75% 1RM, 80% 1RM and 85% 1RM) to predict the percentage of performed repetitions from relative loss of MPV have been provided in the results section. These equations can be easily implemented in a spreadsheet or software application to estimate the actual level of effort being incurred in each training set, thus allowing better monitoring of the resistance exercise stimulus.

One strength of the present study was that, by monitoring repetition velocity and adjusting the actual loads to be lifted from the load (%1RM)-velocity relationship for the BP exercise [11, 24], we made sure that all participants used a very similar relative load (%1RM) in each session. In fact, the maximal difference in the fastest MPV of the set between individuals was $0.04\,m \cdot s^{-1}$ for the 8 loads used (▶ **Table 1** and ▶ **Table 5**), which represents a maximal variation of 2.0–3.3% in relative load [11]. Previous studies that analyzed the pattern of repetition velocity decline during a single set to muscle failure against different loads [14, 15] did not use the

▶ **Table 3** Study I. Correlation coefficients for the relationships observed between the number of performed repetitions in each set to failure and several anthropometric and mechanical variables.

Load (%1RM)	BM (kg)	Height (m)	AL (m)	MPV_{BEST} ($m \cdot s^{-1}$)	MPV_{LAST} ($m \cdot s^{-1}$)	Loss of MPV (%)	Load (kg)	$1RM_{est}$ (kg)	$1RM_{est}$/BM
50% (~0.93 $m \cdot s^{-1}$)	0.20	−0.17	−0.25	0.35	0.17	−0.15	−0.17	−0.12	−0.32
55% (~0.86 $m \cdot s^{-1}$)	−0.44 *	−0.43 *	−0.46 *	0.05	−0.34	0.34	−0.50 *	−0.35	−0.04
60% (~0.79 $m \cdot s^{-1}$)	−0.17	−0.43 *	−0.41	0.29	0.06	−0.05	−0.61 **	−0.53 *	−0.56 *
65% (~0.71 $m \cdot s^{-1}$)	0.21	−0.10	−0.25	0.04	−0.21	0.21	0.18	0.41	0.48 *
70% (~0.62 $m \cdot s^{-1}$)	−0.12	−0.50 *	−0.44 *	−0.24	−0.19	0.17	−0.45 *	−0.49 *	−0.56 *
75% (~0.54 $m \cdot s^{-1}$)	−0.11	−0.12	−0.35	0.37	−0.17	0.22	−0.17	0.16	0.25
80% (~0.47 $m \cdot s^{-1}$)	0.09	0.01	−0.19	0.35	−0.08	0.07	0.00	−0.02	−0.13
85% (~0.39 $m \cdot s^{-1}$)	0.07	0.16	0.16	0.08	−0.58 **	−0.56 **	−0.09	0.05	−0.01

BM: body mass; AL: arm length; MPV_{BEST}: mean propulsive velocity of the fastest (usually first) repetition in the set; MPV_{LAST}: mean propulsive velocity of the last repetition in the set; $1RM_{est}$: estimated one-repetition maximum

Statistically significant correlation: * $p < 0.05$; ** $p < 0.01$

velocity of the first (fastest) repetition of the set to determine loading magnitude (%1RM), i. e., these studies did not check whether the actual load used in the MNR tests corresponded to the proposed or prescribed load. Furthermore, the mean velocity of the last repetition in the set was very similar for all loads used (0.12–0.14 $m \cdot s^{-1}$) in this study, and it was well in agreement with that reported for the 1RM load in this exercise (~0.14–0.15 $m \cdot s^{-1}$) [6, 11, 15], which indicates that the participants actually performed the exercise sets to muscle failure.

The average number of repetitions completed during the 8 MNR tests decreased as loading magnitude increased (▶ **Table 1**; ▶ **Fig. 1a**). This was an expected result and was in accordance with previous research [15, 22]. A finding worth noting was that the number of repetitions completed against each load (50–85% 1RM) showed a large inter-individual variability (CV ~20%; ▶ **Table 2**), with the minimum number of completed repetitions representing ~50% of the maximum number of repetitions for the 8 loads used (▶ **Table 1**). This finding was somewhat surprising considering that participants had RT experience and were exercising against the same relative load in each session. In general, no clear significant correlations were found between the number of completed repetitions against each load and the anthropometric or mechanical variables assessed in the present study (▶ **Table 3**). Previous studies also failed to find significant relationships between the number of repetitions completed against submaximal loads and 1RM or 1RM/body mass [14, 28]. However, some research has found that the number of repetitions completed showed a positive relationship with the number of capillaries per mm^2 of muscle cross-sectional area [28], and a negative correlation with the percentage of type II fibers [5]. Therefore, it appears that the large variability observed in the number of repetitions completed against a given load (%1RM) may depend, at least in part, on the specific muscle characteristics and training background of each participant [21].

The very close relationship observed in the present study between the relative loss of repetition velocity and the percentage of performed repetitions with respect to the maximum possible number (▶ **Fig. 2a**), makes it possible to determine with considerable precision the percentage of repetitions that has been completed as soon as a given percentage of velocity loss is detected. Thus, for example, our results indicate that when an individual reaches a 30% loss of MPV in a BP set against loads of 50–70% 1RM, he would have completed ~50% of the possible repetitions (leaving the other 50% undone); if, however, the set is continued until a 50% loss of MPV is incurred, the percentage of completed repetitions would have then increased to ~75% (leaving only 25% of repetitions in reserve) (▶ **Table 4**; ▶ **Fig. 2**). This represents a novel method for monitoring training volume during RT which allows us: (i) to determine the actual degree or level of effort being incurred by an athlete during each exercise set; and (ii) to equalize the level of effort for each subject during RT. The 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 and inertial measurement units).

Unlike the large inter-individual variability (CV ~20%; ▶ **Table 2**) observed for the number of performed repetitions against each load under study (50–85% 1RM), the variability for the percentage of repetitions completed for a given magnitude of MPV loss in the set was much lower (CV: 2.7–11.6%, depending on the percentage of MPV loss incurred; ▶ **Table 2**).

Taken together, our results highlight the practical importance of using the loss of repetition velocity for monitoring the level of effort and the training volume during resistance exercise. In conclusion, the present study has shown that: 1) there exists a very close relationship between the percentage of MPV loss incurred in a set and the percentage of performed repetitions, for loads between 50–85% 1RM, in the BP exercise; 2) this relationship was very similar for all loads, but particularly for those ranging from 50% to 70% 1RM; 3) the number of repetitions performed in a set to failure against different submaximal loads (50–85% 1RM) showed a high inter-subject variability and was, in general, not correlated with any of the anthropometric or mechanical variables assessed; and 4) the percentage of performed repetitions with respect to the maximum possible number that can be completed, when a given magnitude of MPV loss is reached in a set, showed a high absolute reliability.

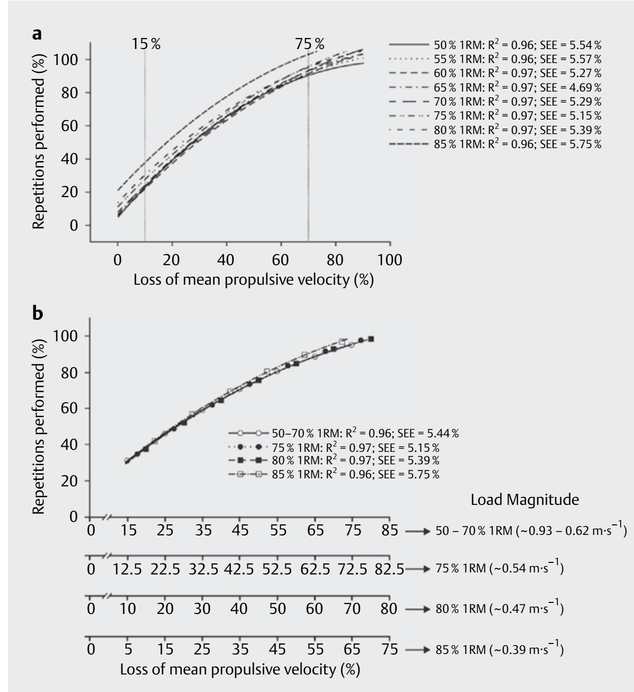
Practical applications

The results of this study contribute to improving our understanding of how the resistance exercise stimulus can be better quanti-

▶ **Table 4** Study I. Percentage of performed repetitions with respect to the maximum possible number that can be completed when a given magnitude of MPV loss is reached in each set to failure against loads of 50–70 % 1RM.

Load (% 1RM)	Loss of MPV (%) **15 %**	**20 %**	**25 %**	**30 %**	**35 %**	**40 %**	**45 %**	**50 %**	**55 %**	**60 %**	**65 %**	**70 %**	**75 %**
50 % (~0.93 m·s⁻¹)	31.2	39.1	46.4	53.3	59.7	65.6	71.0	75.9	80.3	84.2	87.6	90.6	93.0
55 % (~0.86 m·s⁻¹)	31.4	39.3	46.7	53.6	60.1	66.1	71.6	76.7	81.3	85.5	89.2	92.4	95.1
60 % (~0.79 m·s⁻¹)	29.8	37.3	44.3	51.1	57.4	63.4	69.0	74.2	79.1	83.6	87.7	91.4	94.8
65 % (~0.71 m·s⁻¹)	32.1	39.8	47.1	53.9	60.4	66.4	72.0	77.2	82.0	86.3	90.3	93.8	96.9
70 % (~0.62 m·s⁻¹)	31.5	38.7	45.7	52.3	58.6	64.5	70.1	75.4	80.4	85.0	89.3	93.3	96.9
Mean ± SD	31.2 ± 0.8	38.8 ± 1.0	46.0 ± 1.1	52.8 ± 1.2	59.2 ± 1.2	65.2 ± 1.2	70.7 ± 1.2	75.9 ± 1.2	80.6 ± 1.1	84.9 ± 1.1	88.8 ± 1.1	92.3 ± 1.3	95.4 ± 1.6
CV (%)	2.7	2.5	2.3	2.2	2.1	1.9	1.7	1.5	1.4	1.3	1.3	1.4	1.7

MPV: mean propulsive velocity; CV: coefficient of variation



▶ **Fig. 2** Study I. Relationship between the magnitude of velocity loss incurred in a set and the percentage of completed repetitions with respect to the maximum –to failure– number of repetitions that can be performed in the bench press. **a** The percentage of performed repetitions for a given magnitude of velocity loss reached (from 15 to 75 %) was similar for loads between 50 and 70 % 1RM, but it was progressively greater for 75, 80 and 85 % 1RM. **b** For loads of 75, 80 and 85 % 1RM, a lower magnitude of velocity loss over the set should be allowed (~2.5, ~5 and ~10 % less, respectively) in order to achieve a similar percentage of repetitions completed when compared to loads of 50–70 % 1RM.

fied and more effectively monitored and prescribed. Coaches and strength and conditioning professionals usually prescribe training volume as repetitions per set. However, the present findings indicate that the number of repetitions that can be completed against a given relative load (%1RM) present a large variability between individuals. Thus, if during resistance training 2 subjects are required to perform the same number of repetitions per set, it is likely that they could be exercising with a different degree or level of effort. This is so because the percentage of repetitions completed with respect to the maximum could considerably differ for each subject. The findings of the present study suggest that, rather than prescribing a fixed number of repetitions to perform with a given load, training volume during RT should be monitored using the magnitude of velocity loss attained in each exercise set because it is closely linked to the actual level of effort being incurred. Thus, first repetition's mean velocity (which is intrinsically related to the %1RM being used) and the percent velocity loss to be reached during each set are the 2 variables that should be prescribed and monitored during an RT program aimed to optimize athletic performance. According to this novel, velocity-based approach to RT, each set should be stopped when the desired percentage of velocity loss (e. g., 15, 30 or 40 %) has been reached. The magnitude of velocity loss should be set in advance depending on the specific training

▶ **Table 5** Study II. Descriptive variables for the 2 exercise sets to failure performed against a load of 60 % 1RM.

	MPV_{BEST} (m·s⁻¹)	MPV_{LAST} (m·s⁻¹)	Loss of MPV (%)	Rep	Load (kg)
Trial 1	0.80 ± 0.01 (0.77–0.81)	0.14 ± 0.04 (0.07–0.22)	81.4 ± 5.3 (71.3–90.9)	17.6 ± 3.7 (11–25)	49.7 ± 10.5 (28–67)
Trial 2	0.79 ± 0.01 (0.77–0.81)	0.14 ± 0.05 (0.07–0.23)	81.8 ± 5.7 (73.5–91.1)	17.6 ± 3.2 (11–25)	49.3 ± 10.7 (27–67)

Data are mean ± SD (range)

Rep: number of completed repetitions in the set; MPV_{BEST}: mean propulsive velocity of the fastest (usually first) repetition in the set; MPV_{LAST}: mean propulsive velocity of the last repetition in the set

▶ **Table 6** Study II. Percentage of repetitions completed and absolute reliability for each magnitude of MPV loss reached in a set to failure against 60 % 1RM.

Loss of MPV (%)	Trial 1	Trial 2	CV (%)
15 %	29.6 ± 4.6	30.0 ± 3.3	6.6
20 %	37.1 ± 5.2	37.4 ± 3.8	6.0
25 %	44.2 ± 5.6	44.6 ± 4.2	5.5
30 %	51.0 ± 5.8	51.3 ± 4.5	5.1
35 %	57.4 ± 5.9	57.8 ± 4.7	4.7
40 %	63.5 ± 5.9	63.8 ± 4.7	4.3
45 %	69.3 ± 5.8	69.6 ± 4.5	3.8
50 %	74.7 ± 5.5	75.0 ± 4.3	3.3
55 %	79.8 ± 5.1	80.0 ± 3.9	2.8
60 %	84.6 ± 4.6	84.7 ± 3.4	2.4
65 %	89.0 ± 4.1	89.1 ± 2.9	2.2
70 %	93.1 ± 3.7	93.1 ± 2.6	2.2
75 %	96.8 ± 3.5	96.7 ± 2.7	2.1

MPV: mean propulsive velocity; CV: coefficient of variation

goal being pursued, the particular exercise to be performed as well as the training experience and performance level of the athlete.

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Conflict of Interests

The authors declare no conflict of interest.

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