Movement Velocity as a Measure of Loading Intensity in Resistance Training

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Key words
- bench press
- muscle strength
- 1RM prediction
- isoinertial assessment
- exercise testing
- weight training

Abstract

This study examined the possibility of using movement velocity as an indicator of relative load in the bench press (BP) exercise. One hundred and twenty strength-trained males performed a test (T1) with increasing loads for the individual determination of the one-repetition maximum (1RM) and full load-velocity profile. Fifty-six subjects performed the test on a second occasion (T2) following 6 weeks of training. A very close relationship between mean propulsive velocity (MPV) and load (%1RM) was observed ($R^2 = 0.98$). Mean velocity attained with 1RM was $0.16 \pm 0.04\,m \cdot s^{-1}$ and was found to influence the MPV attained with each %1RM. Despite a mean increase of 9.3% in 1RM from T1 to T2, MPV for each %1RM remained stable. Stability in the load-velocity relationship was also confirmed regardless of individual relative strength. These results confirm an inextricable relationship between relative load and MPV in the BP that makes it possible to: 1) evaluate maximal strength without the need to perform a 1RM test, or test of maximum number of repetitions to failure (XRM); 2) determine the %1RM that is being used as soon as the first repetition with any given load is performed; 3) prescribe and monitor training load according to velocity, instead of percentages of 1RM or XRM.

Introduction

One of the main problems faced by strength and conditioning coaches is the issue of how to objectively quantify and monitor the actual training load undertaken by athletes in order to maximize performance. Several acute training variables have been identified for resistance training program design (exercise type and order, intensity or load, number of repetitions and sets, and rests between sets) [24]. Manipulation of these variables shapes the magnitude and type of physiological responses and, ultimately, the adaptations to strength training [2, 32]. Exercise intensity is generally acknowledged as the most important stimulus related to changes in strength levels [23], and has been commonly identified with relative load (percentage of one-repetition maximum, 1RM) [12]. This approach requires coaches to individually assess the 1RM value for each athlete. Direct assessment of 1RM, however, has some potential disadvantages worth noting. It may be associated with injury when performed incorrectly or by novice subjects and it is time-consuming and impractical for large groups [3, 4, 25]. Furthermore, experience tells us that the actual RM can change quite rapidly after only a few training sessions and often the obtained value is not the subject's true maximum.

An alternative way to prescribe loading intensity is to determine, through trial and error, the maximum number of repetitions that can be performed with a given submaximal weight. For example, 10RM refers to a weight that can be lifted ten times, but no more. Several studies [16, 19, 30] have been conducted to identify the relationship between selected percentages of 1RM and the number of repetitions to failure, establishing a repetition maximum continuum [23]. It is believed that certain performance characteristics are best trained using specific RM load ranges [6, 32]. This method certainly eliminates the need for a direct 1RM test, but it is not without drawbacks either. Although training using exhaustive efforts is common practice in strength training, increasing evidence shows that training to repetition failure does not necessarily improve the magnitude of strength gains and that it may even be counterproductive by inducing excessive fatigue, mechanical and metabolic strain for sub-

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sequent sessions [9,10,18,33,34] as well as undesirable transitions to slower fibre types [12]. Furthermore, after performing the first set to failure the number of repetitions in following sets is reduced, regardless of recovery [29]. Hence, by the second or third set it is likely that the athlete may not be training within the prescribed intensity range. Prediction models for 1RM derived from regression equations based on maximum number of repetitions to failure have also been proposed [3,4,25,28,35] as an alternative to direct 1RM assessment.
The aforementioned limitations suggest trying to find better ways to objectively monitor training load during resistance exercise. Movement velocity is another variable which could be of great interest for monitoring exercise intensity but surprisingly, as some authors have noticed [19,27], it has been vaguely mentioned in most studies. The lack of use of this variable is likely because until recently it was not possible to accurately measure velocity in typical isoinertial resistance training exercises. Thus, most of the research which has addressed velocity of movement in strength training has done so mainly in studies that used isokinetic dynamometry [1,5,7,22] which, unfortunately, is not an ideal or common training setting. The actual velocity performed in each repetition could perhaps be the best reference to gauge the real effort which is being incurred by the athlete, although, to the best of our knowledge, there are yet no studies that have specifically examined this issue. Therefore, the purpose of the present study was to analyze the relationship between movement velocity and relative load (%1RM) in the concentric bench press (BP) in order to assess the possibility of using velocity data to estimate relative load.

Materials and Methods
▼
Subjects
One hundred and twenty young healthy men volunteered to take part in this study. The subjects' mean ± SD age, height, body mass, body fat percentage, and one-repetition maximum (1RM) bench press were: 24.3 ± 5.2 years, 1.80 ± 0.07 m, 78.3 ± 8.3 kg, 13.2 ± 4.1 %, 87.8 ± 15.9 kg, respectively. Subjects' weight training experience ranged from 1.5 to beyond 4 years (2–3 sessions per week). No physical limitations or musculoskeletal injuries that could affect testing were reported. The study met the ethical standards of this journal [14] and was approved by the Research Ethics Committee of Pablo de Olavide University. After being informed of the purpose and experimental procedures, subjects signed a written informed consent form prior to participation.

Testing procedures
All 120 subjects performed an isoinertial strength test (T1) with increasing loads up to the 1RM for the individual determination of the full load-velocity relationship in the BP exercise. A subset of the total sample (56 subjects) performed the same test on a second occasion (T2), following 6-wk of resistance training. During this time each subject trained following his usual routine (2–3 sessions/wk) using free-weights, which included the BP (3–5 sets, 4–12 repetitions, 60–85% 1RM, 2–4 min inter-set rests). Subjects were instructed to avoid training to repetition failure and to perform concentric actions at maximal velocity. A detailed description of the strength testing procedures used in this study has recently been reported elsewhere [31].

Measurement equipment and data acquisition
Height was measured to the nearest 0.5 cm during a maximal inhalation using a wall-mounted stadiometer (Seca 202, Seca Ltd., Hamburg, Germany). Body mass and fat percentage were determined using an 8-contact electrode segmental body composition analyzer (Tanita BC-418, Tanita Corp., Tokyo, Japan).
A Smith machine (Multipower Fitness Line, Peroga, Spain) was used for all tests. An isoinertial dynamometer (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) was used for mechanical measurements. This system consists of a cable-extension linear velocity transducer interfaced to a personal computer by means of a 14-bit resolution analog-to-digital data acquisition board, and custom software. Vertical instantaneous velocity was directly sampled by the device at a frequency of 1 000 Hz. The propulsive phase was defined as that portion of the concentric phase during which the measured acceleration (a) is greater than acceleration due to gravity (i.e. $a \geq -9.81\ \mathrm{m \cdot s^{-2}}$). Mean test velocity was defined as the mean of the velocity values, calculated each 5% from 30–95%1RM, and derived from second-order polynomial fits to load-velocity data for each test.

Statistical analyses
Standard statistical methods were used for the calculation of means, standard deviations (SD) and *Pearson* product-moment correlation coefficients (r). Intraclass correlation coefficients (ICC) were calculated with the one-way random effects model. Coefficients of variation (CV) were calculated as typical error of measurement expressed as a percentage of the subjects' mean score. One-way ANOVA was used to detect differences between subgroups of subjects. *Scheffé* post-hoc test was used to identify the source of any significant differences. The *Kolmogorov-Smirnov* test was applied to determine the nature of the data distribution for the velocity attained with the 1RM load. Relationship between relative load and velocity was studied by fitting second-order polynomials to data. Significance was accepted at the $P \leq 0.05$ level.

Results
▼
Relationship between relative load and velocity
After plotting mean propulsive velocity (MPV) against %1RM and fitting a second-order polynomial to all data points, a very close relationship ($R^2 = 0.98$) between these two variables could be observed (**Fig. 1**). Individual curve fits for each test gave an R^2 of 0.996 ± 0.003 (range: 0.983–0.999; CV = 0.3%). The mean MPV attained with each percentage of 1RM was obtained from these polynomial fits, from 30% 1RM onwards, in 5% increments (**Table 1**).

Influence of the velocity attained with 1RM
Mean velocity attained with the 1RM load (V_{1RM}) was $0.16 \pm 0.04\ \mathrm{m \cdot s^{-1}}$, and followed a normal distribution, ranging from $0.06\ \mathrm{m \cdot s^{-1}}$ to $0.24\ \mathrm{m \cdot s^{-1}}$. A significant, although low, correlation ($r = 0.27$, $P < 0.01$; **Fig. 2**) was found between V_{1RM} and mean test velocity.

Stability in the load-velocity relationship after modifying the 1RM
A subset of 56 subjects performed a retest after 6-wk of training for the purpose of studying the differences that could exist in the MPV attained with each relative load after modifying their max-

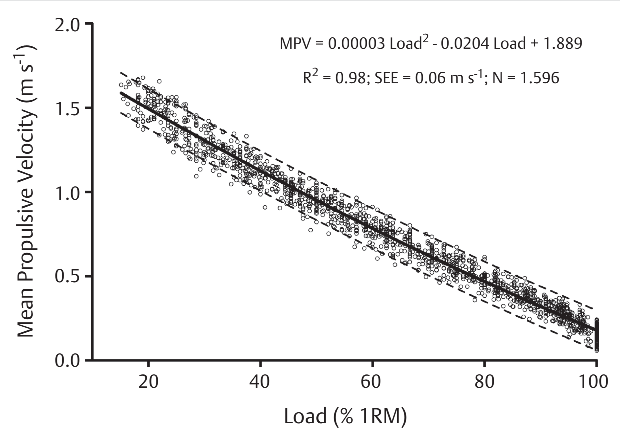

Fig. 1 Relationship between relative load (% 1RM) and MPV directly obtained from 1 596 raw data derived from the 176 incremental tests performed in the BP exercise. Solid line shows the fitted curve to the data, and the dotted lines indicate limits within which 95% of predictions will fall.

Table 1 Changes in mean propulsive velocity ($m \cdot s^{-1}$) attained with each relative load, from initial test (T1) to retest (T2), after 6-wk of training, in the bench press exercise.

Load (%1RM)	T1	T2	Difference (T1–T2)
30%	1.33±0.08	1.33±0.08	0.00
35%	1.24±0.07	1.23±0.07	0.01
40%	1.15±0.06	1.14±0.06	0.01
45%	1.06±0.05	1.05±0.05	0.01
50%	0.97±0.05	0.96±0.05	0.01
55%	0.89±0.05	0.87±0.05	0.01*
60%	0.80±0.05	0.79±0.05	0.01
65%	0.72±0.05	0.71±0.05	0.01
70%	0.64±0.05	0.63±0.05	0.01
75%	0.56±0.04	0.55±0.04	0.01
80%	0.48±0.04	0.47±0.04	0.01
85%	0.41±0.04	0.40±0.04	0.01
90%	0.33±0.04	0.32±0.04	0.01
95%	0.26±0.03	0.25±0.03	0.01
100%	0.19±0.04	0.18±0.04	0.00*

* Does not exactly coincide with T1-T2 due to the shown values being the result of rounding to two decimal places. Values are mean ± SD (N = 56).

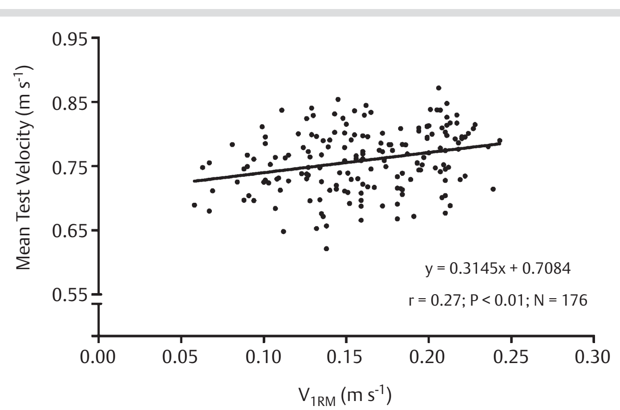

Fig. 2 Correlation between mean velocities attained with the 1RM load (V_{1RM}) and mean test velocity.

imal strength. From T1 to T2, the mean 1RM value improved by 9.3±6.7% (changing from 86.9±15.2 kg to 94.5±15.2 kg). Despite this fact, the difference in mean test velocity was only of $-0.01 \pm 0.05\, m \cdot s^{-1}$ or, when expressed as absolute values, of $0.02 \pm 0.02\, m \cdot s^{-1}$, changing from $0.78 \pm 0.05\, m \cdot s^{-1}$ to $0.76 \pm 0.05\, m \cdot s^{-1}$. ▶ **Table 1** shows the differences in MPV attained with each percentage of 1RM for the 56 subjects who performed twice the BP test. Despite the observed change in 1RM values from T1 to T2, after 6-wk of training, mean ICC for MPV attained with each load (%1RM) was 0.87 (range: 0.81–0.91; CV: 0.0–3.6%; 95% confidence interval: 0.68–0.95). When plotting percentage of change in the 1RM values against the differences between mean test velocity from T1 to T2, a negative and significant correlation could be identified ($r = -0.42$, $P < 0.01$). A positive, but non-significant, correlation ($r = 0.23$, $P = 0.091$) was found when comparing changes in V_{1RM} from T1 to T2 and differences in mean test velocity.

▶ **Fig. 3** provides examples of the load-velocity relationships for three representative subjects. ▶ **Fig. 3a** corresponds to one subject who improved his 1RM value by 11.8% (from 85–95 kg). V_{1RM} in T1 ($0.16\, m \cdot s^{-1}$) was almost identical to that of T2 ($0.14\, m \cdot s^{-1}$), while MPV with each %1RM and mean test velocity remained stable. ▶ **Fig. 3b** shows an extreme case, the subject who showed the greatest change in the load-velocity curve from T1 to T2. He improved his 1RM (14.8%, from 115–132 kg), but V_{1RM} in T2 ($0.06\, m \cdot s^{-1}$) and mean test velocity ($0.69\, m \cdot s^{-1}$) were both considerably lower to those of T1 ($0.17\, m \cdot s^{-1}$ and $0.75\, m \cdot s^{-1}$, respectively). MPV attained with each relative load were lower in T2 than in T1. Finally, the subject whose curves are shown in ▶ **Fig. 3c** did not improve his maximal strength (1RM value slightly decreased by 2.2%, from 112.5–110 kg). For this subject, V_{1RM} in T1 ($0.10\, m \cdot s^{-1}$) and T2 ($0.12\, m \cdot s^{-1}$) were very similar, and mean test velocity was the same on both occasions ($0.73\, m \cdot s^{-1}$). MPV attained with each percentage of 1RM in T1 and T2 were almost identical.

Stability in the load-velocity relationship regardless of individual relative strength

In order to study whether the velocity attained with each %1RM was dependent upon individual strength levels, subjects were ranked according to relative strength ratio (RSR) and the total sample of 176 tests was further divided into four subgroups: group 1 (G1), n = 45, RSR ≤0.97; group 2 (G2), n = 44, 0.97 < RSR ≤1.09; group 3 (G3), n = 44, 1.09 < RSR ≤1.22; and group 4 (G4), n = 43, RSR >1.22. Mean test velocity for G4 was significantly lower ($P < 0.05$) than for all other groups. No significant differences in V_{1RM} were found between groups, although certain tendency towards slightly lower values was detected for the strongest group (G4) (▶ **Table 2**).

Predicting load (% 1RM) from velocity data

A prediction equation to estimate relative load (Load, %1RM) from mean propulsive velocity data (MPV, in $m \cdot s^{-1}$) could be obtained: $Load = 8.4326\, MPV^2 - 73.501\, MPV + 112.33$ ($R^2 = 0.981$; SEE = 3.56% 1RM). In the case that mean concentric velocity (MV) is used, the resulting equation was: $Load = 7.5786\, MV^2 - 75.865\, MV + 113.02$ ($R^2 = 0.979$; SEE = 3.77% 1RM).

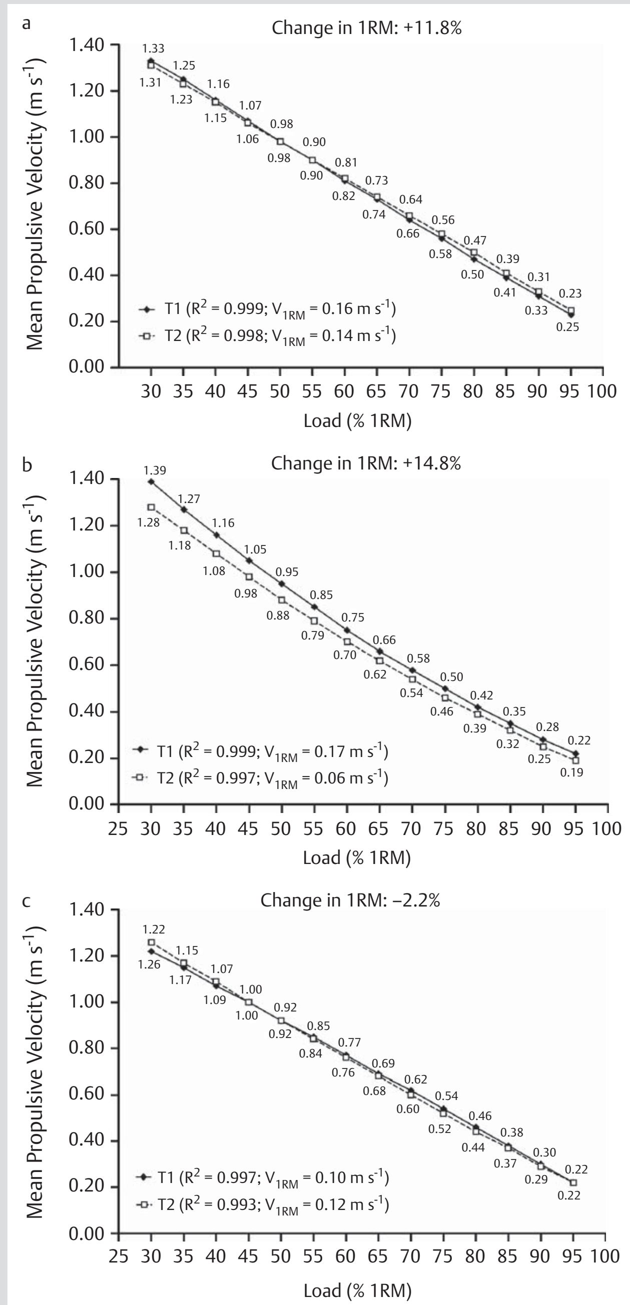

Fig. 3 Load-velocity relationships for three representative subjects in the bench press exercise. Solid (T1) and dashed (T2) lines are second-order polynomial curve fits. (**a**) 1RM increased from 85 kg (T1) to 95 kg (T2); (**b**) 1RM increased from 115 kg (T1) to 132 kg (T2); (**c**) 1RM decreased from 112.5 kg (T1) to 110 kg (T2).

Discussion

The main finding of this investigation was that the mean velocity attained with a given absolute load can be used as a very good estimate of the relative load (%1RM) that load represents. The force-velocity relationship of skeletal muscle is a well-known phenomenon since the work of Nobel laureate A.V. Hill [15] and has been extensively studied under in vitro and in vivo conditions [5,13]. Similarly, the load-velocity relationship has already been described for isoinertial resistance exercise performed with maximal voluntary effort [8,21]. However, the role played by movement velocity has often been overlooked in the everyday practice of strength training. To the best of our knowledge, the present study is the first to examine the relationship between relative load (% 1RM) and mean velocity. Our results highlight the practical importance of considering movement velocity for monitoring training load in resistance exercise.

The extremely close relationship ($R^2=0.98$) observed between relative load and MPV (▶ **Fig. 1**) makes it possible to determine with great precision which %1RM is being used as soon as the first repetition of a set is performed with maximal voluntary velocity. It also allows us to determine the real intensity of effort being incurred by an athlete when using any load from 30% to 95% of 1RM. Furthermore, if repetition velocity is habitually monitored it is possible to determine whether the proposed load (kg) for a given training session truly represents the real effort (%1RM) that was intended.

Table 2 Comparison of mean test velocity and mean velocity attained with the 1RM load (V_{1RM}) between subgroups of different relative strength.

Subgroup	RSR*	Mean Test Velocity ($m \cdot s^{-1}$)	V_{1RM} ($m \cdot s^{-1}$)
G1 (n=45)	0.90±0.07†	0.762±0.050	0.164±0.040
G2 (n=44)	1.04±0.03†	0.768±0.046	0.168±0.037
G3 (n=44)	1.16±0.04†	0.770±0.034	0.163±0.048
G4 (n=43)	1.41±0.18†	0.735±0.056#	0.149±0.044

* RSR: Relative Strength Ratio, defined as 1RM value divided by body mass. † All groups significantly different from each other (P<0.05). # Significantly different from all other groups (P<0.05). Values are mean±SD

Since the observed differences in velocity between each 5% increment in relative load (from 30–100%1RM) vary between 0.07 and 0.09 $m \cdot s^{-1}$ (▶ **Table 1**), it can be estimated that when a subject increases the MPV attained with a given absolute load by 7–9 hundredths of a metre per second, performance (1RM value) would have improved by 5%. The same reasoning would be applicable had the subject decreased the velocity attained against the same absolute load.

The observed values for V_{1RM} are well in agreement with those reported by Izquierdo et al. [19], the only study to our knowledge that has paid attention to the velocity attained with the 1RM. As one could expect, V_{1RM} influences the mean velocity attained with each %1RM. As shown in ▶ **Fig. 2**, as V_{1RM} gets higher, there exists a tendency (r=0.27, P<0.01) towards higher velocities with each %1RM. This may further indicate that some maximum value for V_{1RM} should be established in order for 1RM load to be considered true and valid. This also means that when V_{1RM} is not actually measured, as frequently occurs, the values of mean velocity correspondent to each %1RM, as well as these percentages themselves, can easily differ from the true values. In our study, the observed mean V_{1RM} was 0.16±0.04 $m \cdot s^{-1}$; adding a standard deviation to the mean, the resulting velocity is 0.20 $m \cdot s^{-1}$. Since up to this velocity, the aforementioned tendency towards higher velocities with each %1RM is very low (r=0.17, NS), a practical recommendation is made for only considering as true RM those repetitions whose mean concentric velocity is not greater than 0.20 $m \cdot s^{-1}$ in the BP exercise. As V_{1RM} exceeds this figure, mean velocities attained with each %1RM and relative loads themselves deviate from their true values. Nonetheless, practice shows that sometimes it is not possible for a subject to get V_{1RM} under 0.20 $m \cdot s^{-1}$, but being cognizant of this fact is important for coaches and sport scientists to be able to more precisely adjust the training load. Moreover, everyday training and testing experience tells us that the V_{1RM} value is different for each resistance training exercise.

Another interesting finding of the present study is that MPV attained with each %1RM is not modified when a subject's 1RM value changes after a period of strength training. When 56 athletes performed a retest after 6-wk of training having on average improved their 1RM by 9.3 %, changes in MPV with each %1RM (30–95 %) were minimal, from 0.00–0.01 $m \cdot s^{-1}$ (**Table 1**), despite such a notable change in maximal dynamic strength. These results clearly show that mean velocity attained with each %1RM is a very stable indicator of the actual percentage of 1RM that each load (weight) represents. However, there was a significant tendency ($r = 0.41$, $P < 0.01$) for mean test velocity to decrease with larger improvements in 1RM. This is explained by the fact that as individual performance (1RM) improves, V_{1RM} tends to be slightly reduced (**Table 2**). Thus, the subjects with the highest relative strength (G4 group, RSR = 1.41) reached their 1RM with a slightly, but not significant, lower mean velocity than the rest of subgroups (0.164, 0.168 and 0.163 for G1, G2 and G3, respectively; and 0.149 for G4). By contrast, mean test velocity for G4 was significantly lower than that reached by the less strong groups (**Table 2**). Similar findings have been reported when examining BP and half-squat performance of athletes from sports with different strength demands [17, 19].

Further evidence of the importance of V_{1RM} comes when examining the three representative cases presented in **Fig. 3**. We can conclude that it is precisely V_{1RM} that determines the subtle changes in MPV attained with each %1RM between test and retest. In the first case (**Fig. 3a**), the subject clearly improves his performance (+ 12 %, from 85–95 kg). Since V_{1RM} in T1 and T2 are very similar (0.16 and 0.14 $m \cdot s^{-1}$, respectively), the differences in MPV attained with each %1RM range from 0.00–0.03 $m \cdot s^{-1}$, and mean test velocity only differs in 0.01 $m \cdot s^{-1}$ between T2 and T1 (0.78 and 0.77 $m \cdot s^{-1}$, respectively). However, in the second example (**Fig. 3b**), with a 1RM improvement similar to the previous case (+ 15 %), but with very different V_{1RM} in T1 (0.17 $m \cdot s^{-1}$) and T2 (0.06 $m \cdot s^{-1}$), all MPV are lower in T2 (ranging from −0.11 to −0.03 $m \cdot s^{-1}$) in a similar proportion (~0.07 $m \cdot s^{-1}$), and mean test velocity differs in 0.06 $m \cdot s^{-1}$ between T2 and T1 (0.69 and 0.75 $m \cdot s^{-1}$, respectively). Lastly, when the athlete's 1RM value slightly decreased (-2 %) but maintained a very similar V_{1RM} in T1 and T2, mean test velocities of T1 and T2 were almost identical (**Fig. 3c**).

Velocity seems to be the steadiest parameter in isoinertial strength assessment [20]. Despite the fact that our subjects significantly modified their maximal strength levels as a result of 6-wk of training, the ICC obtained for MPV attained with each %1RM, from 30–95 %, when comparing test and retest were very high (0.81–0.91; CV: 0.0–3.6 %), thus showing the high reliability of the velocity parameter and suggesting its use for strength assessment follow-up.

For testing and evaluation purposes, it is important to consider that the velocity attained with each percentage of 1RM can be slightly different according to the exact method of calculating mean velocities; that is, whether we use mean velocity of the whole concentric portion of the lift (MV) or mean velocity of only the propulsive phase (MPV). This is explained by the fact that as the lifted loads are lighter, the braking phase becomes larger. The larger the braking phase, the greater is the difference between MV and MPV. This means that when using velocity to monitor and/or prescribe loading intensity we must clearly specify the exact parameter that is being used, especially when light loads are used. We advocate the use of MPV because it better represents the true neuromuscular potential of a subject against a given absolute load [31].

Mean velocities attained with each %1RM are very similar to those reported in previous research on the BP exercise [11, 21], but differ from the surprisingly low velocities observed in some studies [8, 26]. Since the exercise protocols used do not seem to be much different, these divergent findings are difficult to explain but might perhaps be attributable to the type of Smith machine and hydraulic braking mechanism used in the latter studies.

Conclusions

The main findings of the present study were that: 1) there exists an inextricable relationship between relative load and mean velocity that allows us to use one to estimate the other with great precision; and 2) mean velocities attained with each %1RM can differ very slightly due to differences in V_{1RM}.

Practical Applications

These findings have important practical applications for the prescription and monitoring of training load in resistance training, making it possible to:

1) Evaluate an athlete's strength without the need to perform a 1RM test or a test of maximum number of repetitions to failure (XRM).
2) 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. This allows us to determine the real effort being incurred when training with loads from 30–95 % 1RM.
3) Prescribe and monitor training load according to velocity, instead of percentages of 1RM, that are highly modifiable on a daily basis; or XRM, which forces us to train to muscle failure to approximately know the %1RM we are working with.

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