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Effects of Four Different Velocity-Based Training Programming Models on Strength Gains and Physical Performance

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Abstract

Riscart-López, J, Rendeiro-Pinho, G, Mil-Homens, P, Costa, RS-d, Loturco, I, Pareja-Blanco, F, and León-Prados, JA. Effects of Four different velocity-based training programming models on strength gains and physical performance. *J Strength Cond Res* 35(3): 596–603, 2021—The aim of this study was to compare the effects of 4 velocity-based training (VBT) programming models (linear programming [LP], undulating programming [UP], reverse programming [RP], and constant programming [CP]) on the physical performance of moderately strength-trained men. Forty-three young (age: 22.9 ± 4.8 years; body mass [BM]: 71.7 ± 7.6; full squat [SQ] relative strength 1.32 ± 0.29) subjects were randomly assigned to LP (gradually increase training intensity and decrease volume), UP (volume and intensity increase or decrease repeatedly), RP (gradually increases volume and decrease intensity), and CP (maintains constant volume and intensity) groups and followed an 8-week VBT intervention using the SQ exercise and monitoring movement velocity for every repetition. All groups trained with similar relative average intensity (67.5% 1 repetition maximum [1RM]), magnitude of velocity loss within the set (20%), number of sets (3), and interset recoveries (4 minutes) throughout the training program. Pre-training and post-training measurements included predicted SQ (1RM), average velocity attained for all loads common to pre-tests and post-tests (AV), average velocity for those loads that were moved faster (AV > 1) and slower (AV < 1) than 1 $m \cdot s^{-1}$ at pre-tests, countermovement jump height (CMJ), and 20-m sprint time (T20). No significant group × time interactions were observed for any of the variables analyzed. All groups obtained similar increases (shown in effect size values) in 1RM strength (LP: 0.88; UP: 0.54; RP: 0.62; CP: 0.51), velocity-load-related variables (LP: 0.74–4.15; UP: 0.46–5.04; RP: 0.36–3.71; CP: 0.74–3.23), CMJ height (LP: 0.35; UP: 0.53; RP: 0.49; CP: 0.34), and sprint performance (LP: 0.34; UP: 0.35; RP: 0.32; CP: 0.30). These results suggest that different VBT programming models induced similar physical performance gains in moderately strength-trained subjects.

Key Words: strength training, dose-response, athletic performance, training periodization, training prescription, velocity loss

Introduction

Programming is considered the manipulation of resistance training (RT) variables (i.e., exercise choice and order, relative intensity, volume, density, and movement velocity, among others) to maximize the target adaptations within each specific training phase (6). A number of RT programming models have been suggested in this regard, such as linear programming ([LP]; which gradually increases training intensity and decreases volume) (12,17), undulating programming ([UP]; in which both volume and intensity increase or decrease repeatedly throughout the training program) (3,32), reverse programming ([RP]; which gradually increases volume and decreases intensity) (33), and constant programming ([CP]; which maintains constant volume and intensity throughout the training program) (38). Although, these RT programming models have been commonly used with different purposes, to date, there has been no consensus on their utilization, differences, and efficacy (9,18,37).

Indeed, 2 recent meta-analyses have suggested that different RT models may potentially have similar effects on strength adaptations (13,43). However, it should be noted that previous studies comparing different RT programming models have determined the training intensity based on the percentage-based training method, which prescribes the exercise load based on the 1 repetition maximum (1RM) test, usually performed at pre-training (3,16,24,34,40,41,43,44). Because the actual 1RM may not correspond to the values assessed at pre-training due to the regular fluctuations in maximum strength (26,28) (i.e., impairments induced by fatigue or improvements evoked by adaptations), it cannot be ensured that the relative load (i.e., percentage of 1RM [%1RM]) used in each training session truly represent the intended intensity (11,37).

Velocity-based training (VBT) is a novel and practical RT method proposed to rapidly monitor and prescribe relative loads (11,36). It has been demonstrated that the velocity attained during the concentric phase can be used to precisely determine the RT intensity because of the close relationships observed between %1RM and

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mean propulsive velocity (MPV) in multiple exercises (e.g., bench press, full squat [SQ], parallel squat, and half squat exercises; $R^2 \geq 0.92$ in all exercises) (11,22,37). Therefore, by monitoring repetition velocity, it is possible to determine in real time and with great accuracy the %1RM being used and adjust the load according to the individual changes in strength that usually occur during a RT program. In fact, it has been demonstrated that there is a similar or greater increase in both strength and jump capacities after a VBT compared with a traditional percentage-based training program even when the VBT approach accumulated a lower training volume (9). Moreover, although individual load-velocity relationships may provide more accurate estimations of %1RM than general equations (30), both methods resulted in improvements in squat 1RM and countermovement jump (CMJ) height after 6 weeks of RT (general equations: 1RM: 7.2%; CMJ: 4.3%; individual equation: 1RM: 9.7%; CMJ: 6.6%) (8).

In addition to the relative load, another variable that should be considered when designing RT programs is the "level of effort," which may be defined as "the relationship between the number of repetitions performed within a set and the maximum number of repetitions that could be completed (11,36). In this regard, the velocity loss (VL) within the set, calculated as the relative difference between the velocity of the fastest and the lasted (usually the slowest) repetition (36), has been shown to have a strong relationships ($R^2 = 0.93–0.97$) with the "level of effort" (35). A VL of 20% means that the athlete has performed ~50% of the possible repetitions for SQ exercise (35). Accordingly, a given VL threshold has been associated with the respective percentage of completed repetitions in relation to the maximum number that could be completed. Thus, using the VL within the set rather than prescribing a fixed number of repetitions with a given load seems to be an important step toward a more rational and comprehensive characterization of the training stimulus compared with a more traditional training configuration. In an attempt to find the optimal level of effort during the set in the SQ exercise, previous research has revealed that VL thresholds about 10–20% provide the greatest improvements in both strength and physical performance (26,27,34). As a consequence, by means of movement velocity monitoring, it is possible to determine and adjust the RT intensity and the level of effort with high precision, in real time and on a daily basis.

Despite the practical advantages of VBT, no previous study has compared the effects of different VBT programming models (i.e., linear, undulating, and reverse, among others) on strength and physical performance. Therefore, the aim of this study was to analyze the effects of 4 VBT schemes (LP vs. UP vs. RP vs. CP) on the sprint, jump, and strength capacities of 46 moderately strength-trained subjects. Considering the previous studies on this topic (13,20,43), it was hypothesized that all programming models would induce similar performance adaptations in young moderately strength-trained men because they would be performed under similar intensities, volume, level of effort (i.e., VL in the set), and interset rest periods.

Methods

Experimental Approach to the Problem

An experimental research design was used to examine the effects of 4 VBT programs differing in the model of programming in the SQ exercise: LP vs. UP vs. RP vs. CP. Subjects trained twice a week during 8 weeks. Sessions were conducted in a research laboratory under the supervision of experienced investigators, at the same time of day (±1 hour) and under similar environmental conditions (~20° C and ~60% humidity). Subjects were required not to engage or participate in any other type of strenuous physical activities or competitive events throughout the investigation. All groups were assessed on 2 distinct occasions: the week before (pre-training) and after (post-training) the VBT intervention. Subjects were motivated to give maximal effort with strong verbal encouragement during all testing and training sessions. Training compliance was 100% for all subjects who completed the intervention.

Subjects

Forty-six young moderately strength-trained men volunteered to participate in this study. All subjects were physically active sport science students with RT experience ranging from 1.5 to 4 years and apt to perform the SQ exercise (age range: 18–33 years; No subjects were under 18 years old). After the initial measurements, subjects were matched according to their 1RM and then randomly assigned to one of the 4 groups, which differed only in the VBT programming model. Throughout the study, 3 subjects dropped out because of injury or illness (not related to the training intervention), so the remaining subjects per group were LP (n = 11), UP (n = 10), RP (n = 11), and CP (n = 11). The subjects' characteristics are presented in Table 1. Once informed about the purpose, procedures, and potential risks of the investigation, all subjects gave their voluntary written consent to participate. The present investigation was approved by the Research Ethics Committee of Pablo de Olavide University and conducted in accordance with the Declaration of Helsinki. No physical limitations, health problems, or musculoskeletal injuries that could affect training were found after a medical examination. None of the subjects were taking drugs, medications, or dietary supplements.

Procedures

Anthropometric measurements were taken before the physical testing. Physical performance was assessed at pre-training and post-training using a battery of tests performed in a single session and in a fixed sequence, as described below. Pre-training assessments were conducted after 24 hours of rest, and post-training assessments were conducted after 4 days of rest (after the final training session).

Sprint Test. Two 20-m maximal sprints, separated by a 3 minutes rest, were performed on an indoor running track. Photocell timing gates (Polifemo Radio Light; Microgate, Bolzano, Italy) were placed at the starting line and at a distance of 20 m to determine the time to sprint over 20 m (T20). A standing start was used, with the leading foot placed 1 m behind the first timing gate. Subjects were required to give an all-out maximal effort in each sprint, and

Table 1
Age, height, and body mass of the 4 velocity-based training groups.*†

	LP (n = 11)	UP (n = 10)	RP (n = 11)	CP (n = 11)
Age (y)	23.5 ± 6.3	23.5 ± 5.2	21.9 ± 2.9	22.5 ± 4.7
Height (cm)	177.9 ± 5.4	176.8 ± 7.0	171.8 ± 6.0	180.1 ± 3.6
Body mass (kg)	72.5 ± 7.9	71.2 ± 7.7	67.4 ± 5.6	74.5 ± 9.1

*LP = linear programming (n = 11); UP = undulating programming (n = 10); RP = reverse programming (n = 11); CP = onstant programming (n = 11).
†Data are mean ± SD, n = 43.

the fastest trials were used for analysis. The same warm-up protocol, which incorporated several sets of progressively faster 20 m running accelerations, was followed at pre-test and post-test. Test-retest reliability as measured by the coefficient of variation (CV) was 0.4%. The intraclass correlation coefficient (ICC) was 0.997 (95% confidence interval [CI]: 0.994–0.998).

Vertical Jump Test. A CMJ was performed with the subject standing in an upright position on an infrared timing system (Optojump; Microgate) with the hands on the hips to avoid arm swings. A fast-downward movement was immediately followed by a fast-upward vertical movement as forceful as possible. Each subject performed 5 maximal body mass CMJs, interspersed with 45 seconds rests. The highest and lowest CMJ height values were discarded, and the mean value was used for analysis. Before CMJ assessments, subjects warmed up by performing 2 sets of 10 half squats without additional loads and at moderate velocity, 5 submaximal CMJs, and 3 maximal CMJs. A 2-minute rest period was given between the warm-up and the testing. Coefficient of variation was 1.9%, and ICC was 0.996 (95% CI: 0.993–0.998).

Squat Strength Assessment. A progressive loading test up to the 1RM was performed in the SQ exercise. A Smith machine (Multipower Fitness Line; Peroga, Murcia, Spain) with no counterweight mechanism was used for testing and training. All repetitions were recorded at 1,000 Hz using a valid and reliable linear velocity transducer (T-Force System Ergotech, Murcia, Spain) (36). The SQ was performed with subjects starting from an upright position with the knees and hips fully extended, feet parallel and approximately shoulder-width apart, and the barbell resting across the back at the level of the acromion. Each subject descended in a continuous motion until the maximum range possible for each one (without making butt wink), but always the top of the thighs were below the horizontal plane, then immediately reversed motion to return to the upright position. Unlike the eccentric phase, which was performed at a controlled mean velocity (~0.50–0.90 $m \cdot s^{-1}$), subjects were required to execute the concentric phase at maximal intended velocity. No lifting aids such as weight lifting belts, knee sleeves, or wraps were permitted. First, the subjects warmed up by performing 2 sets of 8 and 6 SQ repetitions (3 minutes rests) with loads of 20 and 30 kg, respectively. The initial load was set at 30 kg and gradually increased by 10 kg increments until the measured MPV was lower than 0.5 $m \cdot s^{-1}$. Three repetitions were executed for the lighter (≤60% 1RM), 2 for the medium (60–70% 1RM), and only one for the heavier loading conditions (80% 1RM). A total of 8.1 ± 1.8 increasing loads were used for each subject, from which 4.3 ± 1.5 were moved faster and 3.8 ± 0.8 slower than 1 $m \cdot s^{-1}$. Strong verbal encouragement was provided to motivate subjects to give a maximal effort. Interset recoveries ranged from 3 minutes (light) to 5 minutes (heavy loads). The 1RM was estimated from the MPV with the heaviest load (>90% 1RM) recorded during the tests, as follows: $100 \times LOAD/-5.961 \times \text{MPV}^2 - 50.71 \times \text{MPV} + 117$, $R^2 = 0.954$ ($SEE = 4.02\%$) (37). Load-velocity relationship in SQ has been shown to be reliable (ICC: 0.908 [95% CI: 0.790–0.960] and CV: 3.8%) (30). Only the best repetition at each load, according to the criterion of fastest MPV, was considered for analysis. All velocity measures reported in this study corresponded to the mean velocity of the propulsive phase of each repetition, which is defined as "the portion of the concentric phase during which barbell acceleration was greater than the acceleration due to gravity" (11). In addition to the 1RM value, 3 other variables derived from this progressive loading test were used to examine the effects of the VBT programming models over different portions of the load-velocity spectrum: (a) average MPV attained against all absolute loads common to pre-tests and post-tests (AV); (b) average MPV attained against absolute loads moved faster than 1 $m \cdot s^{-1}$ at pre-training (AV > 1, "light" loads); and (c) average MPV attained against absolute loads moved slower than 1 $m \cdot s^{-1}$ at pre-training (AV < 1, "heavy" loads).

Resistance Training Programs. The 4 groups trained twice a week (48–72 hours apart), during 8 weeks, performing exclusively the SQ exercise, with the same relative intensity (on average, 67.5% 1RM), magnitude of VL within the set (20%), number of sets (3), and interset recoveries (4 minutes). The only difference among the 4 groups was the training programming. LP, UP, and RP trained under the same relative intensities but with different orders throughout the intervention (from 50 to 85% 1RM). By contrast, CP performed all training sessions with the same relative load (67.5% 1RM), which was, on average, the relative intensity for the other groups. Kinematic characteristics of every repetition during all sessions were recorded using a linear velocity transducer (T-Force System Ergotech). Relative loads were determined from the resulting general equation from the load-velocity relationship for the SQ (37). Thus, a target MPV to be attained in the fastest repetition of each training session was used to estimate the distinct percentages of 1RM. The absolute load (kg) was individually adjusted to match the associated velocity (±0.03 $m \cdot s^{-1}$) with the %1RM prescribed for each respective session. We used a range of 0.03 $m \cdot s^{-1}$ because it has recently been shown that the smallest detectable change in MPV when using the T-Force System is 0.03 $m \cdot s^{-1}$ in SQ exercise (5). In the case that a subject lifted the load faster or slower than the prescribed velocity, the subject rested 3 minutes and then tried again with the new load. A 20% VL threshold was established for all groups because it has been shown that about this VL threshold within the set maximize strength and physical performance gains (26,27). Velocity feedback was given after each repetition. Moreover, subjects were motivated to give maximal effort with strong verbal encouragement during all testing and training sessions. The evolution of training intensities for each group was as follows (Figure 1): (a) LP increased by 5% 1RM every 2 sessions, from 50 to 85% of 1RM; (b) RP decreased by 5% 1RM every 2 sessions, from 85 to 50% of 1RM; (c) UP changed the training intensity in every training session, from 50 to 85% of 1RM; and (d) CP performed all training sessions under the same relative intensity (~67.5% 1RM). A standardized warm-up preceded all RT session as follows: 5 minutes of jogging, 5 minutes of lower-body joint mobilization exercises, 2 sets of 10 SQ repetitions without additional load and at moderate velocity, and 6, 4, and 3 SQ repetitions with 40, 50, and 60% 1RM, respectively, for sessions in which the relative load was equal to or lighter than 70% 1RM. An additional set of 2 SQ repetitions with 70% 1RM was added for sessions in which the relative intensity was heavier than 70% 1RM, and a final set of 1 repetition with 80% 1RM was added for sessions in which the relative intensity was heavier than 80% 1RM. A 3 minutes rest interval was used between all sets. The mean relative intensity (MRI-MPV) was calculated as the average of the weight lifted under all loading conditions, across all sets and repetitions. The evolution of the 1RM across training sessions was estimated from the load-velocity relationship prediction (37), using the fastest repetition at 60% 1RM during the warm-up. This load was selected because it was regularly used in all training sessions by all groups. Therefore, the potential error in the load estimation was similar for all groups.

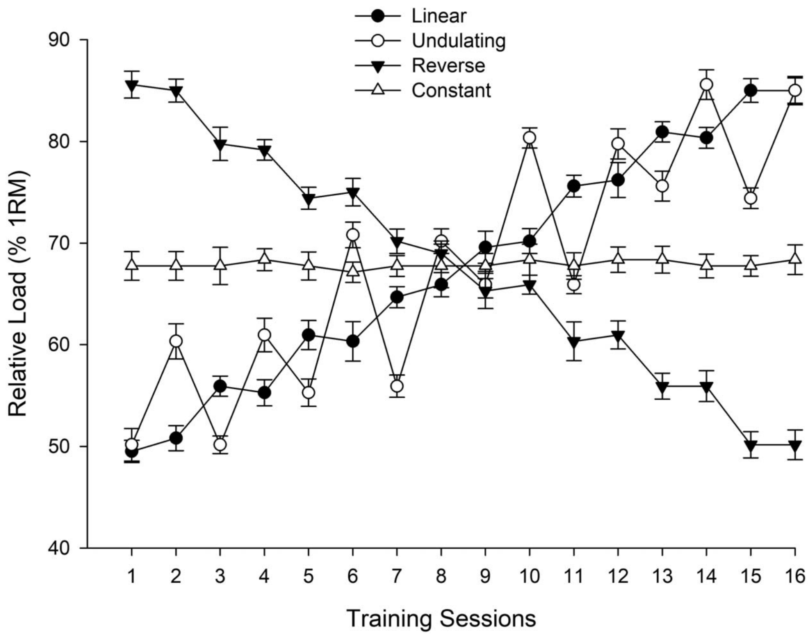

Figure 1. Relative load (%1RM) used by each group during the 16 training sessions. Bars indicate the standard deviation; n = 46; Linear programming (n = 12); undulating programming (n = 10); reverse programming (n = 12); and constant programming (n = 12). 1RM = 1 repetition maximum.

Statistical Analyses

Values are reported as mean ± *SD*. Statistical significance was established at the $p \leq 0.05$ level. The normality of distribution of the variables at pre-training was checked using the Shapiro-Wilk test, and the homogeneity of variance across groups was verified using Levene's test. An ICC with a 95% CI using the one-way random effects model was used to determine the between-subject reliability of the test. Within-subject variation was determined by calculating the CV. Data were analyzed using a 4 × 2 factorial analysis of variance (ANOVA) with Bonferroni's *post hoc* comparisons using one between-group factor (LP, UP, RP, and CP) and one within-group factor (pre-training vs. post-training). In addition, evolution of the estimated 1RM in each training session for each group was analyzed using 4 x 18 factorial ANOVA Bonferroni's *post hoc* comparisons. Effect size (ES) was calculated using Hedge's *g* (14). Probabilities were also calculated to establish whether the true (unknown) differences were lower, similar, or higher than the smallest worthwhile difference or change (0.2 multiplied by the between-subject *SD* (4)). The remaining analyses were performed using the SPSS 18.0 statistical software package (SPSS Inc., Chicago, IL).

Results

Descriptive characteristics of the 4 VBT programming models are reported in Table 2. All groups attained similar fastest MPV (0.88 ± 0.01 $m{\cdot}s^{-1}$, [~67.5% 1RM], calculated as the average of the fastest MPV attained against each relative load in each training session). The CP group trained at a significantly slower average MPV than the other groups ($p < 0.001$). No significant differences were observed in the VL induced by each VBT scheme (~20%) or in the total repetitions performed by each group during the training programs (Table 2). The CP group trained with higher MRI-MPV than the other groups (CP: 0.88 ± 0.01 $m{\cdot}s^{-1}$ [~67.5% 1RM] vs. LP: 0.96 ± 0.02 $m{\cdot}s^{-1}$ [~62.5% 1RM], UP: 0.96 ± 0.01 $m{\cdot}s^{-1}$ [~62.5% 1RM], RP: 0.97 ± 0.02 $m{\cdot}s^{-1}$ [~62.5% 1RM], $p < 0.001$). The UP group performed fewer repetitions per set with 50% 1RM than LP and RP. No significant differences were observed between groups in the rest of the relative intensities.

No significant "group" × "time" interactions were observed for any of the SQ strength variables (1RM: p = 0.18; AV: p = 0.39; AV > 1: p = 0.36; AV < 1: p = 0.49) or physical performance measures (CMJ: p = 0.22; and T20: p = 0.98). After training, all groups presented significant increases in 1RM strength ($p < 0.001$, Table 3). Moreover, all groups exhibited significant improvements in velocity-related variables (obtained from the load-velocity relationship; AV, AV > 1, and AV < 1) and physical performance (CMJ height and T20). The ES values are displayed in Figure 2. The evolution of the estimated 1RM in each training session for the 4 VBT groups is depicted in Figure 3. No significant differences between groups were observed for any training session.

Discussion

This is the first study to compare the effects of 4 different RT programming models (i.e., linear, undulating, reverse, and constant periodization) using the VL threshold VBT approach on the physical performance of moderately strength-trained men. An important aspect of this research was that lifting velocity was measured and recorded for every repetition throughout the intervention, which allowed a strict control of training intensity, volume, and level of effort during all training sessions. Overall, 8 weeks of 4 different VBT programming models produced similar improvements in SQ performance (i.e., 1RM strength and MPV attained against all loads), CMJ height, and 20-m sprint velocity (Table 3). Therefore, our initial hypothesis was confirmed, which could be explained by the similarities in training content (i.e., similar training intensity and volume,

Table 2

Descriptive characteristics of the four 8-week velocity-based full squat training programs performed by the experimental groups.*†

Actually performed	Fastest MPV (m·s^{-1}) [%1RM]	Average MPV (m·s^{-1})	VL (%)	Total rep	MRI-MPV (m·s^{-1}) [%1RM]
LP	0.88 ± 0.01 [~67.5%1RM]	0.85 ± 0.02	20.0 ± 0.7	320.3 ± 93.3	0.96 ± 0.02 [~62.5% 1RM]
UP	0.88 ± 0.01 [~67.5% 1RM]	0.85 ± 0.01	20.1 ± 0.4	263.0 ± 60.3	0.96 ± 0.01 [~62.5% 1RM]
RP	0.88 ± 0.01 [~67.5%1RM]	0.85 ± 0.02	20.3 ± 1.0	315.4 ± 85.5	0.97 ± 0.02 [~62.5%1RM]
CP	0.88 ± 0.01 [~67.5%1RM]	0.77 ± 0.01***	20.3 ± 0.5	231.8 ± 65.5	0.88 ± 0.01*** [~67.5% 1RM]

Actually performed	Rep per set with 50% 1RM	Rep per set with 55% 1RM	Rep per set with 60% 1RM	Rep per set with 65% 1RM	Rep per set with 67.5% 1RM	Rep per set with 70% 1RM	Rep per set with 75% 1RM	Rep per set with 80% 1RM	Rep per set with 85% 1RM
LP	11.8 ± 3.7	10.4 ± 2.6	8.6 ± 2.6	6.7 ± 3.1		5.5 ± 2.3	4.2 ± 1.4	3.5 ± 1.3	2.6 ± 1.1
UP	9.3 ± 2.4*	8.6 ± 2.0	6.8 ± 1.5	5.5 ± 1.3		4.6 ± 1.6	3.7 ± 1.1	3.0 ± 0.9	2.4 ± 0.6
RP	12.3 ± 4.1	9.8 ± 3.0	8.0 ± 3.4	6.9 ± 2.9		5.2 ± 1.7	4.5 ± 1.4	3.5 ± 1.1	2.3 ± 0.7
CP					4.8 ± 1.6				

*LP = linear programming (n = 11); UP: undulating programming (n = 10); RP = reverse programming (n = 11); CP = constant programming (n = 11); MPV = mean propulsive velocity; Fastest MPV = average of the fastest repetition measured in each session, which corresponds to the prescribed training intensity (%1RM); 1RM = 1 repetition maximum Average MPV = Average MPV attained throughout the training intervention; VL = velocity loss in the set calculated as a percent loss in mean velocity from; the fastest to the slowest repetition of each set; Total Rep = total number of repetitions performed throughout the training program; MRI-MPV = mean relative intensity, calculated as the average of the weight lifted under all loading conditions, across all sets and repetitions; Rep per set with a given %1RM = average number of repetitions performed in each set with each of the relative loads used (50–85%1RM).

†Data are presented as mean ± SD, n = 43. Significant differences with respect to the other 3 groups: *$p < 0.05$, ***$p < 0.001$.

level of effort, and interset rest periods) among the VBT programming models.

From the pioneering studies of Matveyev (23) concerning the theory of training periodization, the optimal programming model to maximize strength development has been extensively debated (31,42). In this study, similar increases in 1RM values were observed for all VBT schemes (LP, UP, RP, and CP; 17.3, 10.9, 18.0, and 15.3%, respectively). In agreement with our findings, previous studies have also shown similar improvements in 1RM strength for different programming models (1,10,15,18–21,25,38). Accordingly, a previous meta-analysis detected no significant differences in strength gains between LP and UP programming models (13), whereas a later meta-analysis found that UP induced a more favorable impact on maximum development than LP (37). It is essential to clarify that it could be interpreted that CP did not follow a periodized program, focused on a central periodization principle, which is to incorporate training variation to remove linearity (7). However, this group integrates variation through training intensity because absolute loads were adjusted to daily fluctuations in strength performance (based on the load-velocity relationship). Therefore, subjects belonging to CP did not train always with the same absolute load but rather, using absolute loads adjusted to their daily variations in strength capacity (Figure 3). This fact allow them to progressively train with heavier absolute loads (kg), accomplishing and individualizing the overload principle, which may explain the 1RM improvements observed in this group.

It is worth mentioning that our intention was not only to examine the variations in 1RM strength but also to verify the possible changes (i.e., increases or decreases in MPV) in different zones of the load-velocity spectrum, from light to heavy loads, as well as the potential changes in athletic performance. However, in previous studies, the effect of RT on dynamic muscle performance was limited to the evaluation of maximum strength (i.e., 1RM), disregarding the potential effects of different training approaches on different portions of the load-velocity relationship. Our data indicated similar increases in CMJ height and 20-m sprint velocity for all groups, comparable in magnitude to those previously reported in the literature (2,15,21). In addition, in this study, all groups obtained similar increases in all zones of the load-velocity spectrum. Accordingly, previous studies supported the consistency and stability of this mechanical relationship and indicate that the changes over different force-velocity zones tend to be velocity specific, in contrast to our study, in which training variables were balanced across groups (11,29). Thus, it could be suggested that, regardless of the VBT programming model implemented, the control of certain RT variables (i.e., level of effort, average intensity, number of sets and repetitions, and interset recovery times) may result in similar adaptations in moderately strength-trained men during an 8-week training program.

In most previous studies, repetition velocity during training was not monitored, and the training load (kg) was prescribed

Table 3

Changes in selected performance variables from pre-training to post-training for each velocity-based training group.*†

	LP (n = 11)		UP (n = 10)		RP (n = 11)		CP (n = 11)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1RM (kg)	94.4 ± 17.1	110.7 ± 15.7***	93.3 ± 17.4	103.5 ± 21.7***	94.9 ± 25.3	112.0 ± 25.2***	94.8 ± 26.4	109.3 ± 27.7***
AV (m·s^{-1})	1.00 ± 0.08	1.13 ± 0.08***	0.98 ± 0.07	1.07 ± 0.07***	1.00 ± 0.10	1.12 ± 0.08***	1.00 ± 0.13	1.13 ± 0.10***
AV > 1 (m·s^{-1})	1.29 ± 0.08	1.35 ± 0.08**	1.26 ± 0.09	1.31 ± 0.09*	1.31 ± 0.10	1.35 ± 0.10*	1.27 ± 0.10	1.35 ± 0.10***
AV < 1 (m·s^{-1})	0.66 ± 0.04	0.85 ± 0.08***	0.67 ± 0.03	0.82 ± 0.08***	0.68 ± 0.05	0.88 ± 0.10***	0.67 ± 0.06	0.87 ± 0.07***
CMJ (cm)	38.3 ± 5.2	40.3 ± 4.7*	37.2 ± 5.2	40.2 ± 5.0***	38.8 ± 7.2	43.0 ± 8.7***	37.2 ± 7.5	39.9 ± 7.1**
T20 (s)	3.00 ± 0.14	2.94 ± 0.11*	3.03 ± 0.11	2.99 ± 0.10*	2.99 ± 0.14	2.93 ± 0.11*	3.02 ± 0.16	2.97 ± 0.14**

*LP = linear programming (n = 11); UP = undulating programming (n = 10); RP = reverse programming (n = 11); CP = constant programming (n = 11). 1RM = 1 repetition maximum in full squat exercise; MPV = mean propulsive velocity; AV = average MPV attained against absolute loads common to pre-tests and post-tests in the progressive loading test. AV > 1: average MPV attained against absolute loads common to pre-tests and post-tests moved faster than 1 m·s^{-1}; AV < 1 = average MPV attained against absolute loads common to pre-tests and post-tests moved slower than1 m·s^{-1}; CMJ = countermovement jump; T20 = 20-m sprint time.

†Data are mean ± SD, n = 43. Intragroup significant differences from pre to post: *$p < 0.05$, **$p < 0.01$, ***p ˂ 0.001.

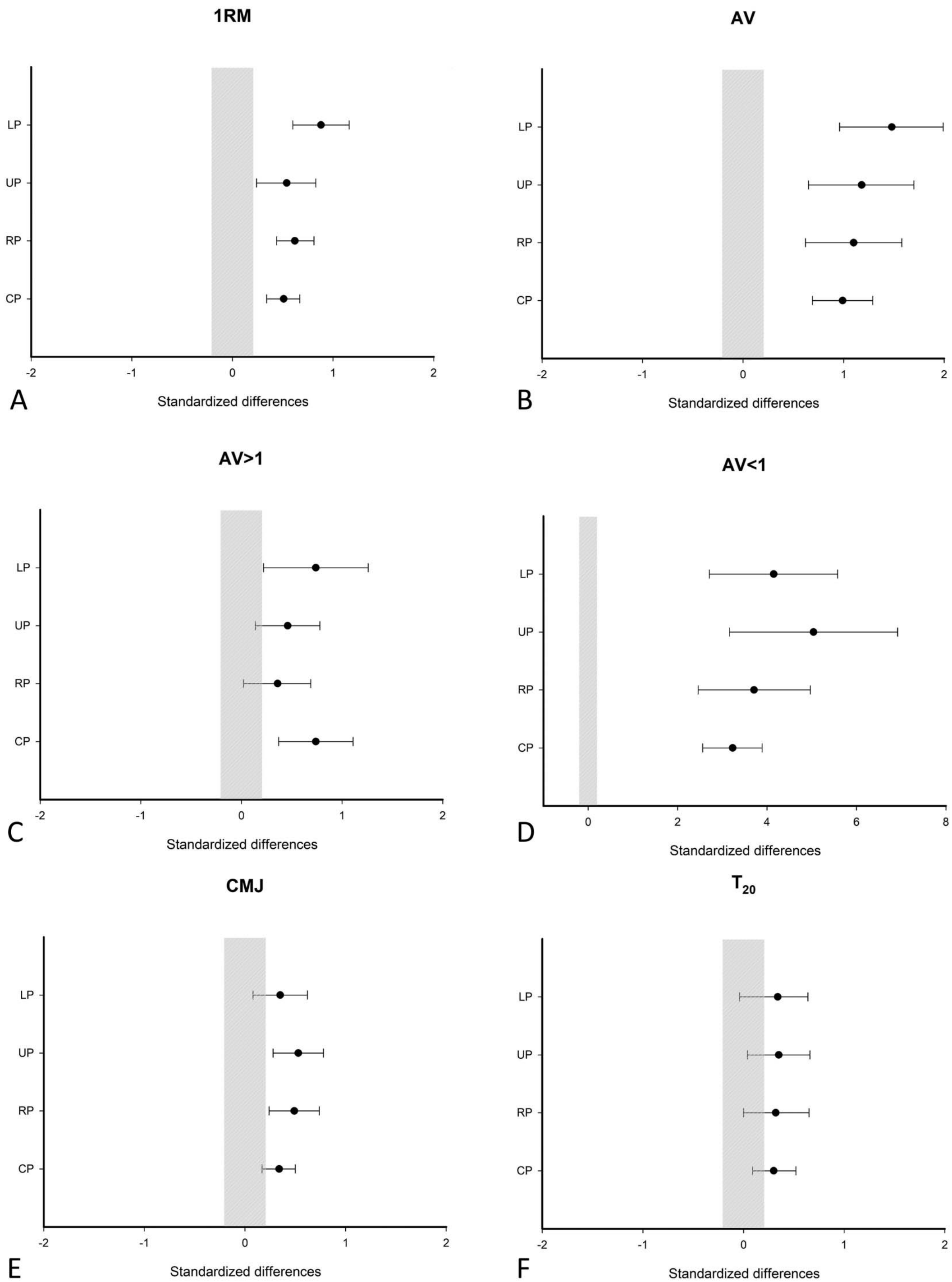

Figure 2. Intragroup changes in (A) 1RM = 1 repetition maximum in full squat exercise; MPV = mean propulsive velocity; (B) AV = average MPV attained against absolute loads common to pre-training and post-training tests in the squat progressive loading test. C) AV > 1 = average MPV attained against absolute loads moved faster than 1 $m \cdot s^{-1}$ at pre-training; (D) AV < 1 = average MPV attained against absolute loads moved slower than1 $m \cdot s^{-1}$ at pre-taining; (E) CMJ = countermovement jump; and F) T20 = 20-m sprint time; for LP = linear programming (n = 11); UP = undulating programming (n = 10); RP = reverse programming (n = 11); CP = constant programming (n = 11). Bars indicate uncertainty in true mean differences with 90% confidence intervals. The trivial area was calculated from the smallest worthwhile change (SWC).

using a relative value (i.e., % 1RM) obtained at pre-training or mid-training measurements (3,12,22,27,33–35,38,39). However, it is important to highlight that the 1RM value usually fluctuates on a daily basis, especially during strength training interventions (26,29). As such, the most relevant contribution of this study is that the relative load was prescribed on a daily basis, by adjusting the absolute load (kg) according to the MPV associated with the %1RM prescribed for the respective training session. This allowed us to precisely control the training intensity and confirm that the relative loads

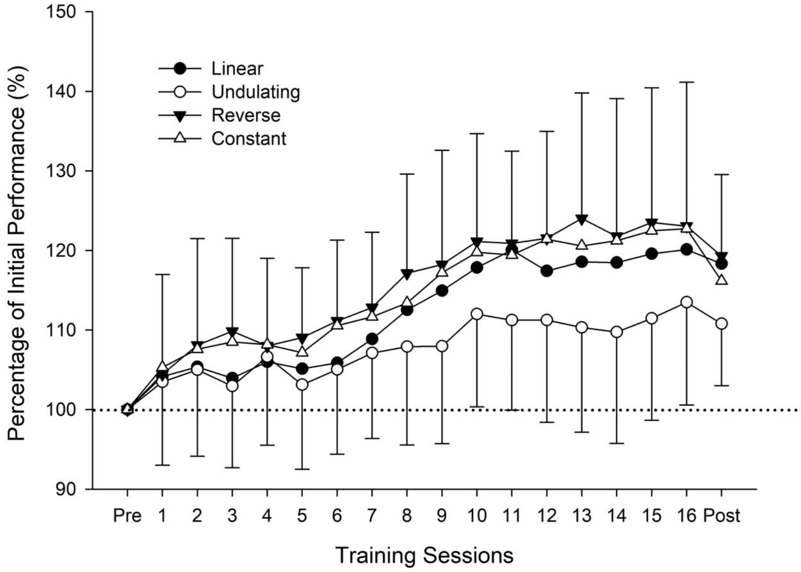

Figure 3. Evolution of 1RM across training sessions with respect to baseline performance for each experimental group. Data are presented as mean ± *SD*. LP = linear programming (*n* = 11); UP = undulating programming (*n* = 10); RP = reverse programming (*n* = 11); CP = constant programming.

represented with great accuracy the %1RM programmed for each VBT session (11,37). Because the change in movement velocity associated with a given load is directly dependent on the force applied onto this load, an increase in MPV may be considered as an indicator of strength improvement. Thus, this approach allowed the measurement of the estimated 1RM in each training session (Figure 3). In agreement with the other parameters analyzed, no statistically significant differences between groups were found in the evolution of the estimated 1RM during the intervention, although UP seems to induce lower improvements in SQ strength throughout an 8-week training period.

Several limitations should be considered when interpreting the results of this study. A Smith machine was used for both testing and training. Although this could be a practical limitation of our design due to most athletes in real-life train using free-weights, using a Smith Machine device provides higher internal validity through a more controlled experimental condition where extraneous variables (e.g., nonvertical displacements) can be limited. The study sample consisted of moderately resistance-trained men; as a consequence, the similar changes observed among the 4 VBT training schemes could be different in top-level athletes. Finally, only 2 training sessions per week were performed. Although most athletes perform strength training twice per week, elite athletes usually train with higher frequency. These higher frequencies may potentially highlight the importance of using different programming models because this likely influences the magnitude and temporal pattern of delayed training effects and, hence, the recovery time required between successive RT sessions. Further studies are needed to examine different VBT programming models with higher training frequencies, especially in top-level athletes during the competitive season.

In conclusion, 4 different VBT models of programming applied over 8 weeks elicited similar improvements in SQ strength (1RM and velocity attained against all loads, from light to heavy), CMJ, and sprint performances. Nevertheless, the evolution of the estimated 1RM throughout the RT intervention seems to be less pronounced in the UP compared with the other VBT programming models.

Practical Applications

Four different VBT programming models (LP, UP, RP, and CP) were equally effective for improving physical performance in moderately strength-trained men. Nonetheless, the time course of SQ strength increases varied between groups, being less pronounced in the UP (compared with LP, RP, and CP). This aspect may be relevant when selecting VBT training strategies according to the time-related criterion (i.e., prioritizing or not prioritizing rapid adaptations in strength-related capacities). Coaches and sport scientists are advised to use the variety of VBT programming models presented here to continuously create effective and attractive training programs for their athletes.

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