NRC Research Press

ARTICLE

# Velocity-based resistance training: impact of velocity loss in the set on neuromuscular performance and hormonal response

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**Abstract:** This study aimed to compare the effects of 2 resistance training (RT) programs with different velocity losses (VLs) allowed in each set: 10% (VL10%) versus 30% (VL30%) on neuromuscular performance and hormonal response. Twenty-five young healthy males were randomly assigned into 2 groups: VL10% ($n$ = 12) or VL30% ($n$ = 13). Subjects followed a velocity-based RT program for 8 weeks (2 sessions per week) using only the full-squat (SQ) exercise at 70%–85% 1-repetition maximum (1RM). Repetition velocity was recorded in all training sessions. A 20-m running sprint, countermovement jump (CMJ), 1RM, muscle endurance, and electromyogram (EMG) during SQ exercise and resting hormonal concentrations were assessed before and after the RT program. Both groups showed similar improvements in muscle strength and endurance variables (VL10%: 7.0%–74.8%; VL30%: 4.2%–73.2%). The VL10% resulted in greater percentage increments in CMJ (9.2% vs. 5.4%) and sprint performance (–1.5% vs. 0.4%) than VL30%, despite VL10% performing less than half of the repetitions than VL30% during RT. In addition, only VL10% showed slight increments in EMG variables, whereas no significant changes in resting hormonal concentrations were observed. Therefore, our results suggest that velocity losses in the set as low as 10% are enough to achieve significant improvements in neuromuscular performance, which means greater efficiency during RT.

**Novelty**

- The VL10% group showed similar or even greater percentage of changes in physical performance compared with VL30%.
- No significant changes in resting hormonal concentrations were observed for any training group.
- Curvilinear relationships between percentage VL in the set and changes in strength and CMJ performance were observed.

*Key words:* muscle adaptations, full squat, physical performance, resistance training, EMG, muscle strength, endocrine response.

**Résumé :** Cette étude compare les effets de deux programmes d'entraînement en résistance (« RT ») avec différentes pertes de vitesse (« VL ») autorisées dans chaque séance : 10 % (« VL10 % ») vs 30 % (« VL30 % ») sur les réponses neuromusculaire et hormonale. Vingt-cinq jeunes hommes en bonne santé sont répartis aléatoirement en deux groupes: VL10 % ($n$ = 12) et VL30 % ($n$ = 13). Les sujets suivent pendant 8 semaines (2 séances par semaine) un programme de RT basé sur la vitesse en effectuant uniquement l'exercice d'accroupissement complet (« SQ ») à 70–85 % 1RM. La vitesse de répétition est enregistrée dans toutes les séances d'entraînement. Avant et après le programme RT, on évalue un sprint de course de 20 m, un saut avec contre-mouvement préparatoire (« CMJ »), 1RM, l'endurance musculaire et l'électromyogramme (« EMG ») pendant l'exercice SQ et les concentrations hormonales au repos. Les deux groupes présentent des améliorations similaires dans les variables de force musculaire et d'endurance (VL10 %: 7,0–74,8 %; VL30 %: 4,2–73,2 %). Le groupe VL10 % présente des augmentations en pourcentage plus importantes du CMJ (9,2 % vs 5,4 %) et au sprint (–1,5 % vs 0,4 %) que le groupe VL30 % même si, pendant le programme RT, le groupe VL10 % a effectué moins de la moitié des répétitions que le groupe VL30 %. De plus, seul le groupe VL10 % présente de légères augmentations des variables EMG alors qu'aucun changement significatif des concentrations hormonales au repos n'est observé. Par conséquent, nos résultats suggèrent que des pertes de vitesse dans les séances aussi faibles que 10 % sont suffisantes pour obtenir des améliorations significatives des performances neuromusculaires, ce qui signifie une plus grande efficacité pendant le programme RT. [Traduit par la Rédaction]

**Les nouveautés**

- Le groupe VL10 % présente un pourcentage similaire ou même plus élevé de changements des performances physiques comparativement au groupe VL30 %.
- Aucun changement significatif des concentrations hormonales au repos n'est observé dans les groupes d'entraînement.
- Des relations curvilinéaires entre le pourcentage de VL dans les séances et les changements de résistance et de performance CMJ sont notées.

Received 5 November 2019. Accepted 27 January 2020.

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*Mots-clés :* adaptations musculaires, accroupissement complet, performance physique, entraînement en résistance, EMG, force musculaire, réponse endocrinienne.



## Introduction

Training volume during resistance training (RT) is a key factor in determining the strength, hypertrophy, neural, and athletic performance adaptations that occur after a training program (Kraemer and Ratamess 2004; Pareja-Blanco et al. 2017*c*). Traditionally, it has been suggested that RT should be conducted to muscle failure to maximize strength and muscle mass gains (Ahtiainen et al. 2003; Kraemer and Ratamess 2004). However, an increasing number of investigations (Davies et al. 2016; Gonzalez-Badillo et al. 2005; Izquierdo et al. 2006; Pareja-Blanco et al. 2017*c*; Sampson and Groeller 2016) appear to indicate that completing the maximal number of repetitions in each set may not be a necessary stimulus to produce greater increments in muscle strength compared with lower training volumes. Indeed, training to muscle failure induces a high level of mechanical, metabolic, and hormonal stress (Gonzalez-Badillo et al. 2016; Moran-Navarro et al. 2017; Pareja-Blanco et al. 2017*b*; Sanchez-Medina and Gonzalez-Badillo 2011), and it appears that the continuous use of this type of RT results in a significant decrement in the rate of force development (Andersen et al. 2010) and, consequently, a reduction in the ability to perform high-speed actions such as jumps and sprints (Pareja-Blanco et al. 2017*c*). However, although recent studies clearly suggest discarding training to muscle failure, the optimal volume during RT for improving performance in muscle strength and other motor skills is still unknown.

Several authors have hypothesized that there may be a curvilinear relationship (an inverted "U"-shaped curve) between training volume and gains in muscle strength and physical performance (Busso 2003; Gonzalez-Badillo et al. 2005; Kuipers 1996). This relationship indicates that there is a minimum volume (volume *threshold*) for each load magnitude range to induce neuromuscular improvements. From that minimum volume threshold, a progressive increase in training volume will be accompanied by an increase in strength gains, up to a certain limit, beyond which an increase in training volume will not produce additional benefits in terms of muscle strength. Even if a certain training volume value is exceeded, it is likely that gains in strength and physical performance will decrease (Busso 2003; Gonzalez-Badillo et al. 2005; Kuipers 1996). Thus, one of the main aims of coaches and sports scientists should be to look for the minimum and maximum volume thresholds (numbers of repetitions per set) that produce improvements in physical performance.

Studies analyzing acute mechanical, metabolic, and hormonal responses to different RT protocols (Gonzalez-Badillo et al. 2016; Moran-Navarro et al. 2017; Pareja-Blanco et al. 2017*b*; Sanchez-Medina and Gonzalez-Badillo 2011) have shown exponential increments in plasma ammonium, cortisol, prolactin (PRL), growth hormone (GH), and creatine kinase concentrations, along with a decrease in heart rate variability, when one-half of the possible repetitions within a set is exceeded. These changes are indicative of a high degree of fatigue, stress, muscle damage, and muscle catabolism, so it has been proposed that this volume limit (half of the possible repetitions) should not be exceeded during RT when the aim is to improve neuromuscular performance (Gonzalez-Badillo et al. 2016; Pareja-Blanco et al. 2017*b*; Sanchez-Medina and Gonzalez-Badillo 2011). In accordance with this hypothesis, it has been found that performing half of the possible repetitions within each training set produces similar or even higher increases in strength, power, and physical performance than those achieved after performing the maximum number of repetitions per set (Izquierdo et al. 2006). Similarly, a recent study using a velocity-based RT approach (Pareja-Blanco et al. 2017*c*) in full-squat exercise (SQ) showed that performing repetitions until reaching a 20% velocity loss (VL) in the set (approximately half the maximum possible number of repetitions per set (Rodriguez-Rosell et al. 2019)) was more effective in inducing strength and vertical jump gains compared with performing repetitions until reaching 40% VL in the set (repetitions to, or very close to, muscle failure (Rodriguez-Rosell et al. 2019)), although the latter group resulted in greater hypertrophic response. The results of these studies (Izquierdo et al. 2006; Pareja-Blanco et al. 2017*c*) seem to confirm the hypothesis that performing more than half of the possible repetitions during RT does not produce greater benefits for neuromuscular performance. However, these previous studies (Izquierdo et al. 2006; Pareja-Blanco et al. 2017*c*) only analyzed 2 repetition ranges: ~20% VL (half of the repetitions possible) versus ~40% VL (muscle failure), leaving a wide spectrum of percentage VL in the set unanalyzed. Therefore, whether velocity losses lower or slightly higher than 20% induce better beneficial effects on physical performance still remains unknown.

It has been suggested that changes in hormonal homeostasis during RT play a relevant role in the synthesis of proteins and the development of muscle strength (Hoppeler 2016; Kraemer and Ratamess 2005; Marx et al. 2001). Acute hormonal responses after different RT protocols have been widely analyzed (Gonzalez-Badillo et al. 2016; Pareja-Blanco et al. 2017*b*; Rubin et al. 2005), whereas the chronic effects have received less scientific attention (Kraemer and Ratamess 2005). This may be because most hormones show a strong acute response that is reversed several hours after exercise (Gonzalez-Badillo et al. 2016; Pareja-Blanco et al. 2017*b*). However, it also seems that RT maintained for long periods could produce alterations in resting hormonal concentrations, indicating that these hormones could also be used as biomarkers of chronic muscle stress induced by RT (Kraemer and Ratamess 2005). Most studies analyzing chronic changes in baseline hormonal concentrations have used training protocols conducted to muscle failure in each set (Ahtiainen et al. 2003; Kraemer and Ratamess 2005; Kraemer et al. 1999), showing different results depending on the hormone analyzed and the load magnitude used. To the authors' knowledge, there has been only 1 study (Izquierdo et al. 2006) comparing the effect of 2 RT programs that differed in the number of repetitions completed in each training set on resting hormonal concentration. This study showed increments in insulin-like growth-factor 1 (IGF-1) and no changes in testosterone and cortisol concentrations for the muscle failure training group, whereas the group that performed half of the maximal possible repetitions showed increments in testosterone and decrements in cortisol concentration, which is associated with a positive anabolic-catabolic balance (Izquierdo et al. 2006). Thus, it seems that changes in serum hormonal concentrations in resting conditions are related to the volume or level of effort induced during RT. However, considering that we only know of 1 study with these characteristics, it appears that further investigations are needed to clarify the chronic effect of RT with different degrees of fatigue (i.e., magnitudes of VL) on resting hormonal concentrations.

On the other hand, increments in muscle strength are also associated with changes in neural factors, mainly in the first weeks of training, where the increase in strength is not related to the morphological changes in the muscle (Moritani and deVries 1979). Evidence of adaptive changes in neural function with RT have been analyzed using surface electromyogram (EMG). Several studies have showed changes in EMG variables after an RT program, even in athletes highly trained in RT, which indicates the high level of plasticity of the neural system (Hoppeler 2016). Most studies have analyzed the changes in muscle EMG during isometric contractions or against a 1-repetition maximum (1RM) load, showing significant changes in EMG amplitude (root mean square (RMS), integrated EMG (iEMG), mean average voltage) or mean and median power frequency after different RT programs (Aagaard et al. 2002; Buckthorpe et al. 2015; Sampson and Groeller 2016; Ullrich et al. 2015). However, to the best of our knowledge, no studies have yet analyzed the changes in EMG variables against different absolute loads following RT with different degrees of fatigue, quantified using the VL achieved in the set.

Therefore, in an attempt to obtain further knowledge about the minimum stimulus required to induce strength improvements and the physiological factors that determine changes in physical performance, the aim of the present study was to compare the effects of 2 RT programs with different degrees of fatigue or levels of effort in each set (10% vs. 30% VL) on neuromuscular performance and hormonal responses. Based on previous studies, we hypothesized that improvements in strength and motor skill performance will be similar or even greater for the RT program allowing only a 10% VL compared with 30% VL, which will also be accompanied by an increase in muscular electrical activity. In contrast, it is expected that RT with 30% VL will induce greater muscle damage and worse anabolic-catabolic balance than RT with 10% VL.

## Materials and methods

**Participants**

Twenty-six healthy men volunteered to take part in this study. Participants were physically active sport science students with RT experience ranging from 1 to 3 years (1–3 sessions per week) and they had been injury-free for at least 6 months before participating in this study. After initial evaluation, participants were matched according to their estimated 1RM in the SQ exercise and then randomly assigned into 2 groups depending on the magnitude of VL allowed during the set: 10% (VL10%) or 30% (VL30%). As a result of illness not related to the training intervention, 1 participant from the VL10% was excluded from the study. Thus, 12 participants in the VL10% group (age: 22.8 ± 3.1 years, body mass: 75.1 ± 10.3 kg, height: 1.77 ± 0.08 m) and 13 participants in the VL30% group (age: 22.2 ± 2.7 years, body mass: 74.0 ± 9.1 kg, height: 1.76 ± 0.07 m) remained for statistical analyses. No physical limitations, health problems, or musculoskeletal injuries that could affect the testing were reported. The study was conducted according to the *Declaration of Helsinki* 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.

## Experimental design

A quantitative, longitudinal experimental study was designed to compare the effects of 2 RT programs, differing only in the VL allowed in each training set (10% vs. 30%), on physical performance, hormonal responses, and changes in muscle EMG. For this, 25 young healthy men were allocated into 2 groups: VL10% ($n = 12$) and VL30% ($n = 13$). Both experimental groups trained twice a week (with 72 h rest between sessions) during an 8-week training period, using only the SQ exercise. The characteristics of RT programs were the same for both experimental groups, differing only in the magnitude of the percentage of VL achieved in each training set: 10% versus 30%. All training sessions were conducted in a research laboratory under the direct supervision of the investigators and under controlled environmental conditions (~20 °C and ~60% humidity). The participants trained on the same days of the week (either Monday and Thursday or Tuesday and Friday) and at the same time of the day (±1 h) to avoid possible factors that could interfere in the results of the present study. Participants were required not to engage in any other type of strenuous physical activity, exercise training, or sports competition for the duration of the present investigation. All participants were assessed before (Pre) and after (Post) the 8-week training intervention using a battery of tests performed in the following order: 20-m all-out running sprint, countermovement jump (CMJ), a progressive loading test in the SQ exercise, and a fatigue test. In addition, hormonal and EMG responses were measured.

**Testing procedures**

Participants completed a 2-day experimental protocol separated by 48 h. The first testing session was used for anthropometric assessments, medical examinations, and taking resting blood samples. For this, participants arrived at the laboratory in a well-rested condition and a fasted state. During the second testing session, each participant performed a 20-m sprint test, a vertical jump test (CMJ), a progressive loading test, and a fatigue test in the SQ exercise. Before the physical performance assessment, all participants carried out a general standardized warm-up consisting of 5 min of running at a self-selected intensity, 5 min of joint mobilization exercises, followed by 3 sets of progressively faster 30-m running accelerations. Exactly the same testing protocol was carried out during both Pre and Post testing sessions. Testing sessions were performed in the same laboratory at the same venue and the same time of day (±1 h) for each participant, under the same environmental conditions (~21 °C and ~60% humidity). At least 3 experienced researchers supervised the testing sessions to ensure correct and consistent techniques were used during all tests. Strong verbal encouragement was provided during all tests to motivate participants to give a maximal effort.

***Running sprint test***

Participants carried out 2 maximal 20-m running sprints (3-min rest) on a synthetic indoor running track and the best of both attempts was kept for analysis. The specific warm-up protocol consisted of one 0–40-m sprint at 80% effort, two 0–30-m sprints at 90% effort, and one 0–20-m sprint at maximal effort. Photocell timing gates (Wireless training timer; Microgate, Bolzano, Italy) were placed at 0, 10, and 20 m so that the times to cover 0–10 m (T10) and 0–20 m (T20) could be determined. A standing start, with the lead-off foot placed 1 m behind the first timing gate, was used. The coefficients of variation (CVs) for test–retest reliability for T10 and T20 were 1.8% and 1.0%, respectively. The intraclass correlation coefficients (ICCs) were 0.90 (95% confidence interval (CI): 0.78–0.95) for T10, and 0.97 (95% CI: 0.94–0.99) for T20.

***CMJ test***

A CMJ was performed with the participant standing in an upright position on an infrared timing system (Optojump System; Microgate) with hands on the hips to avoid arm swings. A fast downward movement was immediately followed by a fast upward vertical movement as high as possible, all in 1 sequence. Five trials were completed with a 45-s rest between each trial. The highest and lowest values were discarded, and the resulting mean value was kept for analysis. The specific warm-up consisted of 2 sets of 10 repetitions of the squat exercise without extra load (2 min rest), 5 CMJs at progressive intensity (20-s rest), and 3 maximal CMJs (30-s rest). The CV was 1.6% and the ICC was 0.99 (95% CI: 0.99–1.00).

***Progressive loading test in the SQ exercise***

A detailed description of the SQ testing protocol has been recently provided elsewhere (Sánchez-Medina et al. 2017). Testing was performed on a Smith machine (Multi-power Fitness Line, Peroga, Murcia, Spain). The participants performed the SQ from an upright position, descending (eccentric phase) in a continuous motion until the posterior thighs and calves made contact with each other, then immediately reversed the motion and ascended back to the starting position. The eccentric phase was performed at a controlled velocity (~0.50 – 0.60 m·s$^{-1}$), whereas participants were required to always execute the concentric phase at maximal intended velocity in all repetitions. Verbal information about movement velocity during eccentric phase was provided after each repetition to maintain the bar velocity within the established range. The specific warm-up consisted of 2 sets of 8 and 6 SQ repetitions (3-min rests) with loads of 20 and 30 kg, respectively. The initial load was set at 30 kg for all participants and was gradually increased in 10-kg increments until the mean propulsive velocity (MPV) was lower than ~0.60 m·s$^{-1}$, which corresponds to ~85% 1RM (Sánchez-Medina et al. 2017). During the test, 3 repetitions were executed for light (MPV > 1.10 m·s$^{-1}$), 2 for medium (1.10 m·s$^{-1}$ > MPV > 0.80 m·s$^{-1}$), and only 1 for the heaviest (MPV < 0.80 m·s$^{-1}$) loads. Interset rests ranged from 3 (light) to 5 min (heavy loads). The exact same warm-up and progression of absolute loads were repeated in the Post test for each participant. Only the best repetition at each load, according to the criterion of fastest MPV, was considered for subsequent analysis. The following variables derived from this test were used for analysis: (*i*) The 1RM calculated for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading test, as follows: (100 × load) / (–5.961 × MPV$^2$) – (50.71 × MPV) + 117 (Sánchez-Medina et al. 2017); (*ii*) average MPV attained against all absolute loads common to Pre and Post tests (AV); (*iii*) average MPV attained against absolute loads common to both tests that were lifted faster than 1.00 m·s$^{-1}$ (AV > 1); (*iv*) average MPV attained against absolute loads common to both tests that were lifted slower than 1.00 m·s$^{-1}$ (AV < 1); and (*v*) MPV attained against 30 kg ($MPV_{30}$), 40 kg ($MPV_{40}$), 50 kg ($MPV_{50}$), 60 kg ($MPV_{60}$), 70 kg ($MPV_{70}$), and 80 kg ($MPV_{80}$). The actual 1RM was not measured directly because this procedure presents several potential disadvantages (Gonzalez-Badillo and Sanchez-Medina 2010). A portable force platform FP-500 (T-Force Dynamic Measurement System; Ergotech, Murcia, Spain), which was synchronized with a linear velocity transducer (T-Force Dynamic Measurement System; Ergotech), was used to measure the relevant kinetic and kinematic parameters of every repetition. The voltage signals generated by the linear velocity transducer and the dynamometric platform were recorded by an analog-to-digital data acquisition board (USB 1408FS of Measurement Computing, with 4 analog inputs of 14-bit resolution) and synchronized in real time using custom software. Both devices the linear velocity transducer and the force platform recorded data at a sampling rate of 1000 Hz.

### *Fatigue test*

After finishing the progressive loading test (5-min rest), a lower body muscular endurance was assessed, also using the SQ exercise. The fatigue test was performed against an absolute load that the participants could initially move to ~0.84 m·s$^{-1}$ (~70% 1RM). Thus, before starting the test, 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. During each test, the participants were required to move the bar as fast as possible during the concentric phase of each repetition, from the first repetition until the MPV was lower than 0.50 m·s$^{-1}$ (Supplementary Material S1[1]). The performance in this test was determined as the number of repetitions completed until the first repetition in which the MPV was just less than 0.50 m·s$^{-1}$. To estimate the muscle endurance, a fatigue test during Pre and Post training for each participant was performed with the same absolute load (kg).

### *Knee extensor muscle activation*

During the progressive loading test in the SQ exercise, muscle activity was recorded from the vastus lateralis ($V_{LA}$) and vastus medialis ($V_{ME}$) of the right leg via pairs of bipolar surface electrodes (Blue Sensor N-00-S; Medicotest) with a distance between the electrodes' centers of 22 mm. After careful preparation of the skin by shaving and cleaning with alcohol, surface electrodes were placed over the belly of the muscle parallel to the presumed orientation of the muscle fibers of $V_{LA}$ and $V_{ME}$, according to Surface EMG for Non-Invasive Assessment of Muscles (SENIAM) guidelines (Hermens et al. 2000). All electrode positions were carefully measured for each participant and were marked with henna dye to ensure identical recording sites throughout the 8-week training period to ensure reliable placement of electrodes during testing sessions. The reference electrode was placed on the patella of the same limb. Skin-electrode impedance was assessed on each occasion and maintained at a consistent level for each individual (within 0.5 MΩ), and at a value < 5 MΩ for all participants. EMG signals were synchronized with kinetic and kinematic data by recording at 1000 Hz with the same analogue-to-digital converter and personal computer as the kinetic and kinematic signals. During off-line analysis, the signals were band-pass filtered in both directions between 6 and 500 Hz using a second order Butterworth digital filter. The parameters analyzed in the present study corresponded to the first 500 ms of the concentric phase of the SQ exercise in both muscle $V_{ME}$ and $V_{LA}$. The EMG variables calculated were: RMS, median power frequency ($F_{med}$), and maximal power frequency ($F_{max}$). EMG data were collected using LabChart software version 7.0 (National Instruments Corporation. Austin, Texas, USA), and data analysis was performed off-line using the MATLAB 2011a software environment (MathWorks Inc., Natick, Mass., USA). For comparison between Pre and Post test, EMG values recorded against each absolute load (30, 40, 50, 60, 70, and 80 kg) were normalized to the respective maximal absolute load lifted during the corresponding progressive loading test. Thus, the EMG values corresponding to each absolute load were expressed as percentages of the maximum load lifted in that same test. This normalization was done because absolute EMG values are significantly influenced by factors including the thickness of subcutaneous tissue; the electrode placement (site and orientation); and the method used to shave, abrade, and clean the surface of the skin. These factors can prevent a direct comparison between the values of the Pre and Post test (Hermens et al. 2000; Staudenmann et al. 2010).

### *Analysis of resting hormone and biochemical concentrations*

Resting blood samples were collected between 08:00 and 10:00 h at the first testing session, after a 12-h overnight fast and abstinence from strenuous exercise for ~48 h. Before blood sample collection, participants rested while seated for 30 min. For all participants, blood samples were drawn from an antecubital forearm vein using a 20-gauge needle connected to Vacutainer tubes (BD diagnostics, Spain). Whole blood was centrifuged (Centrifuge 5417R; Eppendorf, Hamburgo, Germany) at 3000*g* (4 °C) for 15 min and the resultant serum was then removed and stored at –20 °C until subsequent analysis. Samples were analyzed in duplicate, thawed only once, and decoded only after the analyses were completed (i.e., blinded analysis procedure). Concentrations of total testosterone, cortisol, GH and PRL were measured using electrochemiluminescence immunoassays on an Elecsys 2010 autoanalyzer (Roche Diagnostics, Indianapolis, Ind., USA). IGF-1 was measured by chemiluminescent immunometric assay on an Immulite 2000 System (Siemens, Los Angeles, Calif., USA). The Troponin T (TnT) was analyzed using third-generation assay TROP T STAT electrochemiluminescence immuno-assays (Elecsys 1010 automated batch analyser, Roche Diagnostics, Lewes, UK). The assay sensitivities were 0.087 nmol·L$^{-1}$, 8.5 nmol·L$^{-1}$, 0.03 μg·L$^{-1}$, 20 μg·L$^{-1}$, 0.047 μg·L$^{-1}$, and 0.01 μg·L$^{-1}$ for testosterone, cortisol, GH, PRL, IGF-1, and TnT, respectively, with intra-assay CV of 2.0%, 1.7%, 2.3%, 2.9%, 1.3%, and 5.4%, respectively. Concentrations are reported

[1]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/apnm-2019-0829.

uncorrected for plasma volume changes because it has been previously demonstrated that receptors in target tissues are exposed to serum hormonal levels (Rubin et al. 2005).

***RT program***

All participants carried out an 8-week velocity-based RT program involving 2 sessions per week (16 total sessions), using only the SQ exercise. The full-squat exercise was chosen as training exercise because this type of exercise induces greater neuromuscular and functional adaptations and lower pain than half- or quarter-squat after prolonged RT period (Hartmann et al. 2013; Pallares et al. 2019). Training variables such as relative intensity (70%–85% 1RM), number of sets (3), recovery time between sets (4 min), and recovery time between sessions (72 h) were the same for both experimental groups. The only difference between groups was the percent velocity loss allowed in each training set: 10% versus 30%. Descriptive characteristics of the RT program are presented in Table 1. Relative loads were determined from the load-velocity relationship for the SQ exercise (Sánchez-Medina et al. 2017). Thus, a target MPV to be attained in the first (usually the fastest) repetition of the first exercise set in each training session was used as an estimation of percentage of 1RM, as follows: ~0.84 $m \cdot s^{-1}$ (~70% 1RM), ~0.75 $m \cdot s^{-1}$ (~75% 1RM), ~0.68 $m \cdot s^{-1}$ (~80% 1RM), and ~0.60 $m \cdot s^{-1}$ (~85% 1RM). Consequently, before starting the first set in each training session, adjustments in the proposed load (kg) were made when needed so that the velocity of the first repetition matched the programmed velocity (± 0.03 $m \cdot s^{-1}$). Once the load (kg) was adjusted, it was maintained for the 3 training sets. Volume in each training set was objectively determined through the magnitude of VL attained over the set (calculated as the percent loss in MPV from the fastest to the slowest repetition) (Rodriguez-Rosell et al. 2019). Thus, the training set was terminated when the prescribed velocity loss limit was reached (Pareja-Blanco et al. 2017*c*; Sanchez-Medina and Gonzalez-Badillo 2011). According to this method, depending on the training group, participants performed repetitions within the set until reaching 10% or 30% VL with respect to the best MPV obtained in such training set. For the VL10% group, the VL was 10% in all training sessions. However, for the VL30% group, the VL followed a progression from 20% to 30%, the average VL during the training program being 29.4 ± 1.3% (Table 1). This progression was used to avoid excessive overload and minimize the risk of injury at the beginning of the training program in the VL30% group. All repetitions for all participants during all sessions were recorded using a linear velocity transducer (T-Force system). Participants received immediate movement velocity feedback while being encouraged to perform each repetition at maximal intended velocity. During all training sessions all participants carried out a general standardized warm-up, which consisted of 5 min of running at a self-selected intensity, 5 min of joint mobilization exercises, followed by 3 sets of progressively faster 30-m running accelerations. The specific warm-up was also the same for both experimental groups and consisted of (*i*) 1 set of 5 repetitions against 50% and 60% 1RM, respectively, for sessions 1–6; (*ii*) 3 sets of 5, 5 and 3 repetitions against 50%, 60%, and 70% 1RM, respectively, for sessions 7–13; and (*iii*) 4 sets of 5, 5, 3, 1 repetitions against 50%, 60%, 70%, and 80% 1RM, respectively, for sessions 14–16. A 3-min rest between the SQ warm-up sets was always used.

**Statistical analysis**

Standard statistical methods were used for the calculation of means, standard deviations, and correlations. The normality of distribution of the variables at Pre was examined with the Shapiro–Wilk test and the homogeneity of variance across groups (VL10% vs. VL30%) was verified using the Levene's test. A 1-way random effects model (model 2.1) ICC with absolute agreement was used to determine relative reliability. Absolute reliability was reported using the CV. The training-related effects were assessed using a 2 (group: VL10% vs. VL30%) × 2 (time: Pre vs. Post) factorial ANOVA with Bonferroni's adjustment. The intra-group effect sizes (ES) were calculated using Hedge's *g* (Hedges and Olkin 1985), as follows: *g* = (mean Post – mean Pre)/pooled SD. The ES for changes between the VL10% and VL30% groups for each dependent variable was calculated as follow: *g* = (mean Pre-Post differences VL10%) – (mean Pre-Post differences VL30%)/pooled SD. Threshold values for assessing magnitudes of standardized effects were 0.20, 0.60, 1.20, and 2.00 for small, moderate, large, and very large, respectively (Hopkins et al. 2009). Statistical significance was accepted at $p < 0.05$. Null hypothesis tests were performed using SPSS software version 17.0 (SPSS, Chicago, Ill., USA).

## Results

Data for all variables analyzed were homogeneous and normally distributed ($p > 0.05$). Compliance with the training program was 100% for both experimental groups. No significant differences between groups (VL10% vs. VL30%) were found at baseline in any of the variables analyzed.

**Training program**

Descriptive characteristics of the training actually performed by the VL10% and VL30% groups are presented in Table 1. The best MPV of the first training set (i.e., relative intensity, %1RM) and the average velocity loss over 3 sets in each training session matched the scheduled training. No significant differences between groups were observed in the best MPV of the first set in each training session. Participants in VL10% trained at a significantly ($p < 0.001$) faster mean velocity than those in VL30% (0.70 ± 0.01 $m \cdot s^{-1}$ vs. 0.63 ± 0.01 $m \cdot s^{-1}$, respectively). The average total repetitions performed with the maximal scheduled load in each training session were significantly greater ($p < 0.001$) for VL30% (228.0 ± 76.6) compared with VL10% (109.6 ± 2.0). There were no significant differences between groups in the number of repetitions completed when MPV was > 0.70 $m \cdot s^{-1}$, whereas the number of repetitions performed against MPV ranges < 0.70 $m \cdot s^{-1}$ was significantly ($p < 0.001$) greater for VL30% compared with VL10% (Supplementary Material S2[1]).

**Strength, jump, and sprint performance**

There was significant time × group interaction ($p < 0.05$) for T10 and T20, whereas no significant time × group interaction was observed for any strength variable or CMJ performance (Table 2; Fig. 1). The between-groups ESs revealed a *small* effect (0.23–0.50) in favour of VL10% compared with VL30% for CMJ, T10, T20, AV > 1, $MPV_{30}$, and $MPV_{40}$, whereas the standardized differences between VL10% and VL30% were *trivial* (0.03–0.16) for the rest of the variables assessed. The VL10% group showed significant Pre–Post changes in all strength variables analyzed ($p < 0.01$–0.001), muscle endurance ($p < 0.001$), CMJ ($p < 0.001$), and sprint performance ($p < 0.05$), whereas VL30% resulted in significant improvements in all variables ($p < 0.05$ – 0.001), except in sprint time (Table 2; Fig. 1). The intra-group ESs for VL10% were *small* (CMJ, T10, T20, and $MPV_{50,60}$), *moderate* (1RM, AV > 1 and $MPV_{30,40,70,80}$), *large* (AV and fatigue test), and *very large* (AV < 1), whereas in the VL30% group the ESs ranged from *trivial* (T10 and T20) to *large* (AV, AV < 1, fatigue test and $MPV_{80}$) depending on the variable assessed.

**EMG**

Changes in RMS, $F_{med}$ and $F_{max}$ are presented in Fig. 2. No significant "time x group" interactions were observed for any EMG variable analyzed. After completing the RT program, both experimental groups showed no significant changes in EMG variables, although VL10% resulted in greater percentual Pre–Post values in RMS, $F_{med}$ and $F_{max}$ (Fig. 2). The VL30% group only showed in a slight increase in $F_{max}$, while the RMS and $F_{med}$ remained practically unchanged (Fig. 2).

**Table 1.** Descriptive characteristics of the squat training program performed by the VL10% and VL30% groups.

| | Session 1 | Session 2 | Session 3 | Session 4 | Session 5 | Session 6 | Session 7 | Session 8 | Session 9 |
|---|---|---|---|---|---|---|---|---|---|
| **Scheduled** | | | | | | | | | |
| Sets × loss (%) | | | | | | | | | |
| VL10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% |
| VL30% | 3×20% | 3×25% | 3×30% | 3×30% | 3×30% | 3×30% | 3×25% | 3×30% | 3×30% |
| Target MPV (m·s$^{-1}$) | ~0.84 | ~0.84 | ~0.84 | ~0.84 | ~0.84 | ~0.84 | ~0.76 | ~0.76 | ~0.76 |
| **Actually performed** | | | | | | | | | |
| Loss (%) | | | | | | | | | |
| VL10% | 11.9±2.0 | 11.2±2.2 | 12.0±2.3 | 10.2±2.1 | 11.3±1.6 | 11.1±2.1 | 10.7±2.1 | 10.9±2.3 | 10.9±1.7 |
| VL30% | 20.3±2.6 | 27.0±3.8 | 29.3±1.8 | 30.4±3.6 | 30.1±3.1 | 30.2±3.1 | 25.9±2.9 | 31.0±3.8 | 30.1±2.6 |
| No. reps | | | | | | | | | |
| VL10% | 2.8±0.6 | 2.7±0.5 | 2.7±0.5 | 2.9±0.8 | 3.1±0.9 | 2.8±0.6 | 2.2±0.5 | 2.3±0.6 | 2.2±0.3 |
| VL30% | 3.8±1.1 | 4.9±1.5 | 5.5±1.9 | 6.3±2.6 | 6.5±2.4 | 6.5±2.8 | 4.8±1.8 | 5.3±2.0 | 5.1±2.7 |
| Reference reps's MPV (m·s$^{-1}$) | | | | | | | | | |
| VL10% | 0.84±0.03 (~70.2% 1RM) | 0.85±0.03 (~69.6% 1RM) | 0.83±0.02 (~71.0% 1RM) | 0.85±0.02 (~69.8% 1RM) | 0.84±0.02 (~70.4% 1RM) | 0.84±0.02 (~70.3% 1RM) | 0.76±0.02 (~75.1% 1RM) | 0.76±0.02 (~75.0% 1RM) | 0.76±0.02 (~75.4% 1RM) |
| VL30% | 0.84±0.03 (~70.3% 1RM) | 0.85±0.03 (~69.6% 1RM) | 0.83±0.02 (~70.6% 1RM) | 0.84±0.03 (~70.3% 1RM) | 0.84±0.02 (~70.2% 1RM) | 0.84±0.03 (~70.4% 1RM) | 0.76±0.02 (~75.1% 1RM) | 0.76±0.02 (~75.1% 1RM) | 0.77±0.02 (~74.6% 1RM) |

| | Session 10 | Session 11 | Session 12 | Session 13 | Session 14 | Session 15 | Session 16 | Overall |
|---|---|---|---|---|---|---|---|---|
| **Scheduled** | | | | | | | | |
| Sets × VL (%) | | | | | | | | |
| VL10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | 3×10% | |
| VL30% | 3×30% | 3×30% | 3×30% | 3×30% | 3×30% | 3×30% | 3×30% | |
| Target MPV (m·s$^{-1}$) | ~0.76 | ~0.68 | ~0.68 | ~0.68 | ~0.60 | ~0.60 | ~0.60 | |
| **Actually performed** | | | | | | | | |
| Loss (%) | | | | | | | | |
| VL10% | 10.1±2.5 | 10.2±2.5 | 10.7±2.6 | 11.4±2.7 | 9.7±2.4 | 11.6±2.0 | 11.0±2.1 | 10.9±0.8 |
| VL30% | 30.6±3.1 | 31.2±3.8 | 31.9±4.8 | 30.4±2.6 | 31.0±4.0 | 30.1±2.8 | 30.9±3.1 | 29.4±1.3 |
| No. reps | | | | | | | | |
| VL10% | 2.2±0.4 | 2.0±0.3 | 2.0±0.3 | 1.9±0.2 | 1.8±0.2 | 1.7±0.2 | 1.7±0.2 | 2.3±0.2 |
| VL30% | 5.8±2.6 | 3.9±2.4 | 4.7±2.3 | 4.3±2.3 | 2.7±1.6 | 3.0±1.2 | 3.4±1.6 | 4.8±1.7 |
| Reference reps's MPV (m·s$^{-1}$) | | | | | | | | |
| VL10% | 0.76±0.02 (~75.1% 1RM) | 0.68±0.02 (~79.6% 1RM) | 0.70±0.04 (~78.5% 1RM) | 0.69±0.03 (~79.3% 1RM) | 0.61±0.02 (~83.9% 1RM) | 0.60±0.03 (~85.0% 1RM) | 0.60±0.02 (~84.9% 1RM) | 0.74±0.01 (~75.7% 1RM) |
| VL30% | 0.76±0.03 (~75.0% 1RM) | 0.68±0.02 (~79.5% 1RM) | 0.68±0.02 (~79.8% 1RM) | 0.69±0.02 (~79.2% 1RM) | 0.60±0.02 (~84.8% 1RM) | 0.60±0.03 (~84.8% 1RM) | 0.61±0.02 (~84.2% 1RM) | 0.74±0.01 (~75.7% 1RM) |

**Note:** Data are means ± SD. Only 1 exercise (full squat) was used in training. 1RM, 1-repetition maximum; MPV, mean propulsive velocity attained with the intended load (%1RM); No. reps, average number of repetitions performed in each training set; VL, magnitude of velocity loss expressed as percent loss in mean repetition velocity from the fastest (usually first) to the slowest (last) repetition of each set; VL10%, group with 10% VL ($n$ = 12); VL30%, group with 30% VL ($n$ = 13).

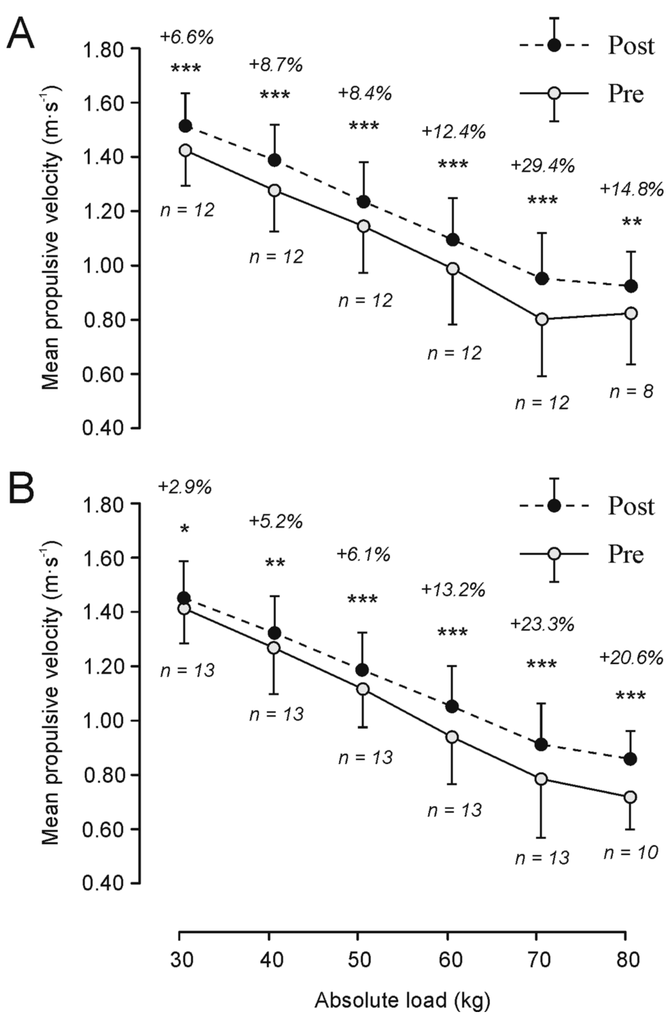
**Table 2.** Changes in selected neuromuscular performance variables from Pre to Post for each training group.

| | VL10% | | | | VL30% | | | | Changes for VL10% vs. VL30% | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Δ (%) | ES (95% CI) | Pre | Post | Δ (%) | ES (95% CI) | Δ (%) | Standardized differences (95% CI) |
| CMJ (cm) | 37.7±5.6 | 41.2±6.1*** | 9.2 | 0.60 (0.26 to 0.93) | 38.4±5.0 | 40.6±6.6* | 5.4 | 0.37 (0.07 to 0.66) | 3.6 | 0.23 (−0.56 to 1.02) |
| T10 (s)† | 1.79±0.07 | 1.76±0.08* | −1.6 | −0.39 (−0.75 to −0.03) | 1.75±0.09 | 1.76±0.08 | 0.7 | 0.14 (−0.20 to 0.48) | 2.2 | 0.50 (−0.29 to 1.30) |
| T20 (s)† | 3.08±0.12 | 3.04±0.12* | −1.5 | −0.38 (−0.7 to −0.04) | 3.06±0.15 | 3.07±0.14 | 0.4 | 0.06 (−0.21 to 0.35) | 1.8 | 0.41 (−0.38 to 1.21) |
| 1RM (kg) | 100.8±24.6 | 116.6±20.7*** | 17.9 | 0.70 (0.32 to 1.08) | 96.6±14.7 | 110.5±15.2*** | 14.9 | 0.93 (0.47 to 1.28) | 2.0 | 0.11 (−0.68 to 0.89) |
| AV (m·s−1) | 1.00±0.09 | 1.11±0.08*** | 11.8 | 1.34 (0.55 to 2.13) | 0.95±0.08 | 1.06±0.09*** | 11.9 | 1.32 (0.49 to 2.16) | 0.5 | 0.06 (−0.72 to 0.85) |
| AV > 1 (m·s−1) | 1.26±0.07 | 1.35±0.08*** | 7.0 | 1.17 (0.45 to 1.88) | 1.26±0.06 | 1.31±0.09* | 4.2 | 0.63 (0.04 to 1.21) | 2.8 | 0.45 (−0.35 to 1.24) |
| AV < 1 (m·s−1) | 0.74±0.04 | 0.88±0.08*** | 19.3 | 2.06 (0.92 to 3.19) | 0.70±0.04 | 0.85±0.09*** | 20.6 | 1.99 (0.96 to 3.01) | −0.7 | −0.07 (−0.86 to 0.71) |
| Fatigue test (reps) | 11.8±3.1 | 19.8±5.0*** | 74.8 | 1.96 (0.89 to 3.03) | 13.9±6.0 | 22.08±4.7*** | 73.2 | 1.53 (0.80 to 2.26) | −1.3 | −0.03 (−0.82 to 0.75) |

**Note:** Data are means ± SD. Δ, Pre–Post change; 1RM, 1-repetition maximum squat strength; AV, average mean propulsive velocity attained against absolute loads common to Pre and Post in the squat progressive loading test; AV > 1, average MPV attained against absolute loads common to Pre and Post that were moved faster than 1 m·s-1; AV < 1, average MPV attained against absolute loads common to pre- and post-test that were moved slower than 1 m·s-1; CI, confidence interval; CMJ, countermovement jump height; ES, effect size; Post, final evaluations; Pre, initial evaluations; reps, number of repetitions completed; T10, 10-m sprint time; T20, 20-m sprint time; VL10%, group with 10% velocity loss ($n$ = 12); VL30%, group with 30% velocity loss ($n$ = 13). †Statistically significant time × group interaction, $p < 0.05$. Intra-group significant differences from Pre to Post: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.



**Fig. 1.** Load–velocity curves in the full-squat exercise for velocity loss of 10% (VL10%) (A) and 30% (VL30%) (B) before (Pre) and after (Post) an 8-week training period. Data are means ± SD. Statistically significant differences within group: *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. The sample size against 80 kg was lower than previous loads because the participants did not need to progress to that load during the initial squat loading test.




## Hormone and biochemical concentrations

There was no significant time × group interaction for any hormonal or biochemical marker analyzed. For both experimental groups, significant changes (VL10%: $p < 0.05$, VL30%: $p < 0.001$) were only observed in TnT. Comparison between groups revealed that changes in TnT protein were significantly greater in VL30% than in VL10% (Table 3).

## Discussion

The main finding of the present study was that an RT program performing repetitions at maximal intended velocity until reaching a 10% VL in the set compared with 30% in the SQ exercise produced similar, or even greater (depending on the variable assessed), increments in muscle strength, muscle endurance, jump, and sprint performance, as well as EMG activity. In addition, the VL30% resulted in greater chronic muscle damage determined by the percentage of increments in TnT plasma concentration. Therefore, in accordance with previous investigations (Pareja-Blanco et al. 2017*a*, 2017*c*), the results of the present study suggest that the degree of fatigue induced during each training set (quantified by the VL) is a determining factor in modulating the neuromuscular adaptations that occur during RT. Specifically, the present study appears to indicate RT allowing a 10% VL in the set is a more efficient than RT with 30% VL for improving physical performance (Supplementary Material S3[1]).

After an 8-week RT program, both experimental groups showed significant enhancements in all strength parameters and fatigue test (Table 2; Fig. 1). Although no significant differences between groups were found, the VL10% resulted in greater percentage changes and intra-group ESs than VL30% for most variables, particularly in MPV attained with light loads (AV > 1 and $MPV_{30-50}$). It is important to note that these changes occurred despite the fact that the VL10% group performed, on average, less than half (48%) of the total repetitions performed by the VL30% group during the training program (109.6 ± 12.0 vs. 228.0 ± 76.6 repetitions for VL10% and VL30%, respectively). These results were especially relevant in the fatigue test, as it has been postulated that performing a greater number of repetitions per set during RT should result in a greater increase in muscular endurance (Bird et al. 2005; Ratamess et al. 2009). However, the percentage change in both groups was similar (VL10%: 74.8%; VL30%: 73.2%; Table 2). In line with our results, other studies comparing RT protocols with different numbers of repetitions per set also showed no significant differences between groups in muscle endurance gains (Anderson and Kearney 1982; Izquierdo et al. 2006). Therefore, in contrast with previous reviews (Bird et al. 2005; Ratamess et al. 2009), it appears that changes in muscle endurance capacity do not di-

**Fig. 2.** Changes in root mean square (RMS) (A and B), median power frequency ($F_{med}$) (C and D), and maximal power frequency ($F_{max}$) (E and F) variables against different absolute loads (30 – 80 kg) in the full squat exercise for both groups velocity loss of 10% (VL10%; top row) and 30% (VL30%; bottom row). Post, after training protocol; Pre, before training protocol. Data are means ± SD.

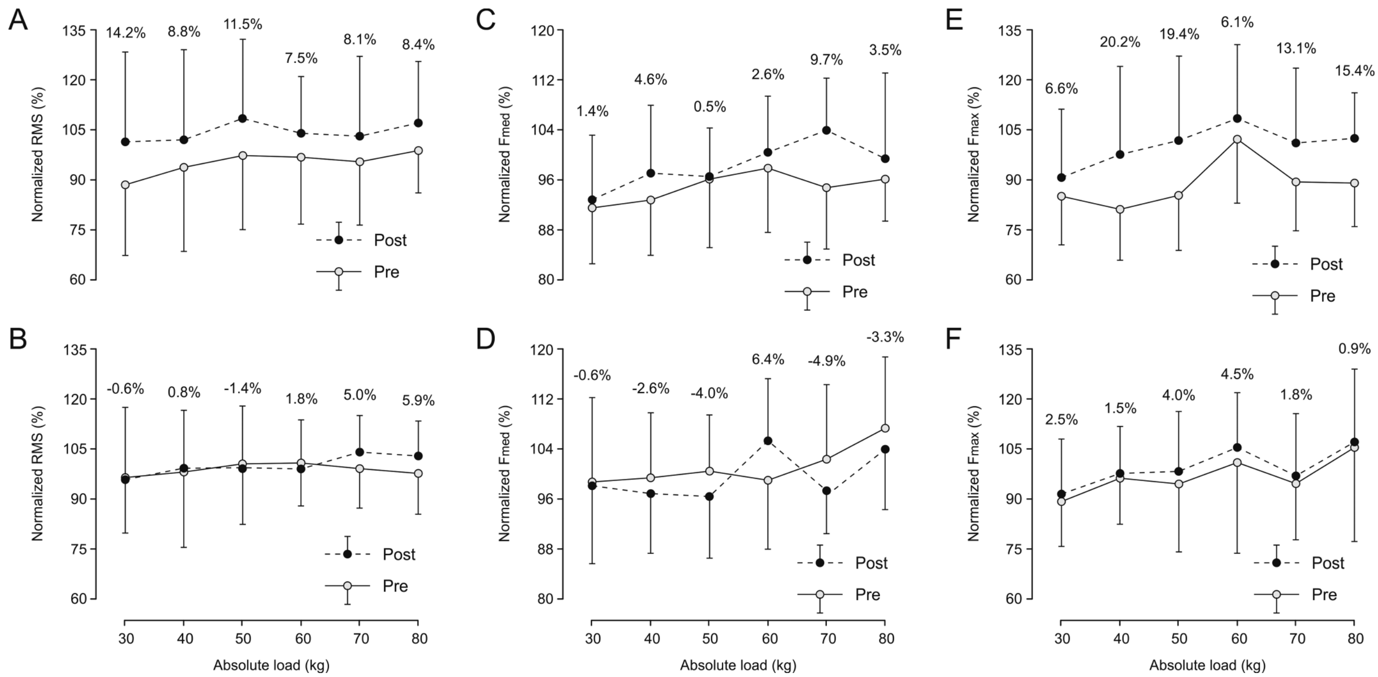



**Table 3.** Changes in resting hormone concentrations from Pre to Post for each group.

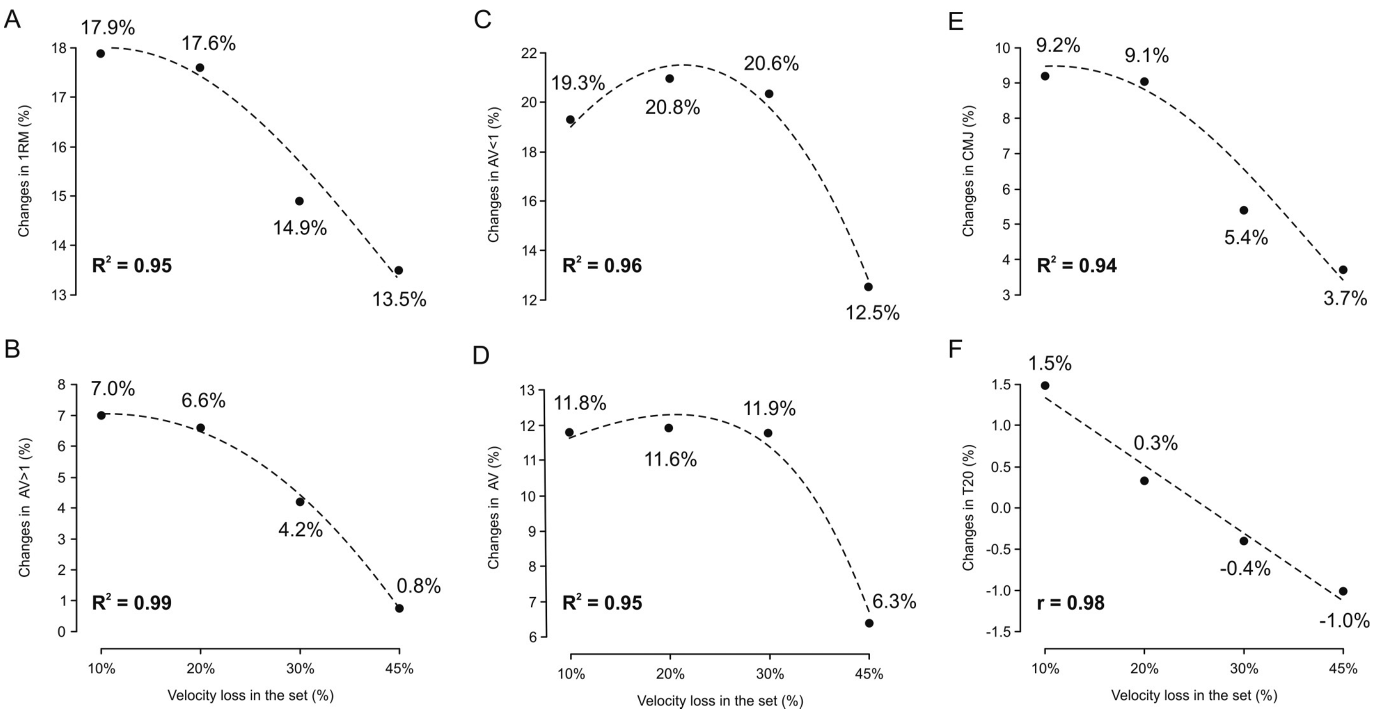
| | VL10% | | | VL30% | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Δ (%) | Pre | Post | Δ (%) |
| Prolactin (ng·mL⁻¹) | 10.8±4.8 | 12.4±4.5 | 18.8 | 12.8±3.7 | 13.5±4.6 | 5.6 |
| GH (ng·mL⁻¹) | 1.44±1.80 | 0.92±1.96 | −69.8 | 1.41±1.38 | 2.13±2.12 | 54.6 |
| IGF-1 (ng·mL⁻¹) | 256.0±75.5 | 261.4±87.1 | 0.5 | 279.5±106.7 | 282.7±101.0 | 2.8 |
| Cortisol (mmol·L⁻¹) | 413.5±197.8 | 417.9±219.3 | 1.5 | 387.7±179.1 | 396.2±159.4 | 8.2 |
| Testosterone (mmol·L⁻¹) | 19.3±8.4 | 20.8±7.6 | 11.9 | 19.1±4.1 | 17.8±5.2 | −4.3 |
| T/C ratio | 0.052±0.041 | 0.056±0.040 | 8.8 | 0.063±0.036 | 0.054±0.029 | −5.3 |
| Troponin T (ng·mL⁻¹) | 4.4±1.9 | 6.9±3.0** | 59.9 | 3.4±1.2 | 7.9±2.6*** | 128.4 |

**Note:** Data are means ± SD. Δ = Pre–Post change; GH, growth hormone; IGF-1, insulin-like growth-factor 1; Post, final evaluations; Pre, initial evaluations; T/C, testosterone–cortisol ratio; VL10%, group with 10% velocity loss (*n* = 12); VL30%, group with 30% velocity loss (*n* = 13). Intra-group significant differences from Pre to Post: **, $P < 0.01$; ***, $P < 0.001$.

rectly depend on the volume of exercise performed during RT. Indeed, our results suggest that increments in muscle endurance depend, at least partially, on increments in maximal strength (1RM), as a linear, positive, and significant relationship ($r = 0.63$; $p < 0.05$) was found between the relative changes in 1RM and the relative changes in fatigue tests.

One of the main aims of coaches and strength and conditioning professionals should be to find more efficient RT methods; that is, obtaining the highest possible gains with the lowest degree of fatigue. Coinciding with our results, several studies have shown that (*i*) performing the maximal number of repetitions in each training set is not the best stimulus to obtain the greatest strength gains (Gonzalez-Badillo et al. 2005; Izquierdo et al. 2006; Pareja-Blanco et al. 2017*c*; Sampson and Groeller 2016); and (*ii*) performing half or less than half of the possible repetitions may induce even greater improvements in physical performance (Izquierdo et al. 2006; Pareja-Blanco et al. 2017*a*, 2017*c*). A recent study (Pareja-Blanco et al. 2017*c*) using velocity-based training for monitoring relative load (70%–85% 1RM) and volume (20% vs. 40% VL), and executing each repetition at maximal intended velocity, found that performing repetitions to reach 20% VL produced similar SQ strength gains as reaching 40% VL, with greater improvements in CMJ. The current study therefore represents a continuation of the work conducted by Pareja-Blanco et al. (2017*c*) as the present study analyzed 2 different magnitudes of VL (10% vs. 30%) to those previously employed, but used the same relative loads. Thus, taken together, the results of both studies suggest that performing even less than half of the possible repetitions (~35%: 109.6 ± 12.0 vs. 310.5 ± 42.0 repetitions for VL10% and VL40%, respectively) with relative loads ranging between 70%–85% 1RM is sufficient to induce significant improvements in muscle strength and endurance (Fig. 3). In fact, the changes in strength variables for VL10% (7.0%–19.3%) were similar to those shown for VL20% (6.6%–20.8%) (Pareja-Blanco et al. 2017*c*), which indicates a greater efficiency for VL10%, as the VL20% group completed a higher average number of repetitions during the training cycle (109.6 ± 12.0 vs. 185.9 ± 22.2 repetitions for VL10% and VL20%, respectively). In addition, the results of both studies confirm the hypothesis that there is a curvilinear relationship (1RM: $R^2 = 0.95$; AV > 1: $R^2 = 0.99$; AV < 1: $R^2 = 0.96$; AV: $R^2 = 0.95$) between training volume and strength improvement (Busso 2003; Gonzalez-Badillo et al. 2005; Kuipers 1996), since performing repetitions to reach 10%–20% VL induced significant increases in maximal strength, endurance and MPV attained against different absolute loads, whereas the percentage of change in these variables decreased progressively as 20% VL in the set was exceeded (Fig. 3).

**Fig. 3.** Relationship between velocity loss in the set and percentage change obtained in 1-repetition maximum (1RM; A), average mean propulsive velocity attained against absolute loads common to Pre and Post that were moved faster than 1 m·s$^{-1}$ (AV > 1) (B), average mean propulsive velocity attained against absolute loads common to Pre and Post that were moved slower than 1 m·s$^{-1}$ (AV < 1) (C), average mean propulsive velocity attained against absolute loads common to Pre and Post in the squat progressive loading test (AV) (D), countermovement jump (CMJ) (E), and sprint time in 20 m (T20) (F) after the resistance training programs against 70%–85% 1RM in the full squat exercise. For these relationships, the results of both the present study and those obtained by Pareja-Blanco et al. (2017*c*) were used. Post, after training protocol; Pre, before training protocol.






Training intervention also resulted in significant improvements in CMJ, T10, and T20 for VL10%, and these percentage changes and ESs were greater than those shown for VL30% (Table 2). These results may be related to the principle of specificity (Behm and Sale 1993*a*, 1993*b*). Although the number of repetitions completed at high velocities (>0.7 m·s$^{-1}$) was similar for both groups, the VL30% group performed more repetitions at low velocities (Supplementary Material S2[1]); consequently, the average total training velocity was significantly lower in VL30% (0.63 ± 0.01 m·s$^{-1}$) than in VL10% (0.70 ± 0.01 m·s$^{-1}$). As indicated in previous studies (Pareja-Blanco et al. 2017*a*, 2017*c*), it seems that these slight differences in average training velocity could be determinants for adaptations produced in high-speed actions such as vertical jumps and acceleration capacity.

Few studies comparing different training volume have examined changes in CMJ and sprint performance (Pareja-Blanco et al. 2017*a*, 2017*c*). These studies showed similar results to those found in the present study, with greater jump (5.3%–9.1%) and sprint (−0.3 to −0.46) improvements with low VL in the set (15%–20%) compared with high VL (30%–40%). As muscle strength, when the data of the present study and that of Pareja-Blanco et al. (2017*c*) were pooled, changes in CMJ also showed a curvilinear relationship ($R^2$ = 0.94) with training volume (Fig. 3E). Similar CMJ gains were obtained with 10% and 20% VL, whereas progressively lower percentage changes were shown as the VL increased (Fig. 3E). Unlike the other variables, a linear relationship ($r$ = 0.98) between changes in T20 and VL in the set was observed (Fig. 3D). Thus, the greatest improvements in T20 were obtained with VL10%, and as VL increased, the performance gains in T20 were progressively decreased. Even, when VL was greater than 20%, RT resulted in negative effects on sprint performance (Fig. 3D). These results appear to indicate that the negative effect of inducing a greater degree of fatigue during each training set on physical performance is manifested to a greater extent with regard to increases in the speed of the action on which the performance is measured. For this reason, it may be important to determine a VL limit within the set during RT as a strategy to avoid unnecessary, slow, and fatiguing repetitions that could be counterproductive in obtaining adaptations related to the rapid force production required in many sports disciplines.

An interesting aspect of this study was that although both training groups showed significant improvements in the MPV attained against different absolute loads, only VL10% showed changes in the EMG variables, although these changes were not statistically significant. In line with the results from the VL10% group, previous studies also showed increments in EMG amplitude (RMS or iEMG) during the 1RM load (Buckthorpe et al. 2015; Sampson and Groeller 2016) or during a maximal isometric contraction (Aagaard et al. 2002; Ullrich et al. 2015), along with an increase in muscle strength after different RT programs. Thus, considering that movement velocity depends directly on the applied force, our results suggest that the changes in EMG variables could explain, at least partially, the increments in MPV against different absolute loads observed in VL10%. Furthermore, increments in muscle activity may also have played an important role in the CMJ and sprint improvements. On the other hand, and in accordance with the results obtained from the VL30% group, several studies have shown no changes in EMG variables after training intervention, despite increases in muscle strength (Ferri et al. 2003; Keen et al. 1994). Therefore, based on the results of the present study, it appears that VL10% and VL30% produced different adaptive responses. There are previous studies supporting the notion that RT programs using high loads and volumes induce greater muscle hypertrophy (Pareja-Blanco et al. 2017*c*), whereas RT programs with low loads and volumes produce decreases in the motor unit recruitment threshold and increases in the firing frequency of the active motor units (Van Cutsem et al. 1998). Therefore, in agreement with previous studies, our results suggest that improvements in VL10% were probably due to neural adaptations. However, both the lack of change in the EMG variables and the increment in the resting concentration of hormones related to tissue remodelling suggest that the changes in muscle strength for VL30% group could have been related to transformations in muscle structure. However, more studies are needed to confirm this hypothesis.

Regarding the biochemical parameters, both experimental groups produced significant changes only in TnT, with VL30% showing significantly greater increments compared with VL10% (Table 3). This protein is related to the muscle damage induced after an endurance training program (Legaz-Arrese et al. 2015). Considering that a greater VL in the set against the same relative load is associated with greater mechanical, metabolic, hormonal, and cardiovascular stress (Gonzalez-Badillo et al. 2016; Pareja-Blanco et al. 2017*b*; Sanchez-Medina and Gonzalez-Badillo 2011), the resting TnT concentration after RT was expected to be higher in VL30% compared with VL10%. However, to the best of our knowledge, this is the first study examining the chronic response of this biomarker to different RT protocols. In this regard, our results suggest that the changes in TnT could be indicative of differences in the degree of fatigue experienced by each experimental group during RT sessions.

On the other hand, no significant changes were observed in the resting concentrations of any hormones analyzed, although VL10% resulted in a slight tendency to increase PRL (18.8%) and testosterone (11.9%), as well as a decrease in GH resting concentration (−69.8%), whereas VL30% only showed relevant percentage changes in GH (54.6%). The results of previous studies analyzing changes in resting concentrations of different anabolic and catabolic hormones after different RT programs are confusing and sometimes contradictory, finding increases (Marx et al. 2001), decreases (Ahtiainen et al. 2003), or, similar to our results, absence of changes (Hakkinen et al. 1985). It is likely that the differences in the training protocols used between studies in terms of relative intensity, volume, type of exercise, and number of exercises performed have influenced the reported results (Kraemer and Ratamess 2005). Specifically, we only know of one other study (Izquierdo et al. 2006) comparing the changes in resting hormone concentrations after RT with different training volumes. In agreement with results obtained for VL30%, Izquierdo et al. (2006) found no significant changes in plasma testosterone (~ −1%) or cortisol (~8%) concentration for training group with maximal numbers of repetitions per set. However, the training group with low numbers of repetitions per set showed significant increments in resting testosterone concentration (~12%) (Izquierdo et al. 2006). This percentage of increment was similar to those showed by VL10% (11.9%), although in our study this change was not statistically significant. In connection, the changes in the testosterone/cortisol ratio have been commonly used to analyze the anabolic–catabolic balance and have been linked to performance improvement (Ahtiainen et al. 2003; Kraemer and Ratamess 2005). However, our results and other previous studies (Hakkinen et al. 1987; Izquierdo et al. 2006) showed significant increments in physical performance without significant changes in the testosterone/cortisol ratio. Therefore, the use of this biomarker remains questionable.

Similar to our results, most studies found that RT had no influence on resting concentrations of GH and IGF-1 hormones (Izquierdo et al. 2006; Kraemer et al. 1999; Marx et al. 2001), despite the importance assigned to these hormones for tissue remodelling in response to resistance exercise (Kraemer and Ratamess 2005; McCall et al. 1999). In contrast, other studies showed increments in IGF-1 after RT with high volumes (Koziris et al. 1999; Marx et al. 2001), suggesting that this factor is relevant for chronic adaptations in this hormone (Kraemer and Ratamess 2005). However, in the present study, although VL30% performed more than half of the repetitions performed by VL10%, no significant or practical changes were observed in either experimental group. Therefore, it appears that further studies are necessary to clarify the influence of different variables such as relative intensity and volume on chronic changes in resting IGF-1 concentration.

## Conclusions

The main findings of the current study were the following:

- The VL10% group showed similar or even greater percentage of changes in muscle strength and endurance, jump, and sprint performance compared with VL30%.
- For VL10%, gains in muscle strength were accompanied by a slightly increase in neural activation of the agonist musculature involved in the SQ exercise ($V_{LA}$ and $V_{ME}$), whereas the EMG activity remained unchanged for VL30%.
- The VL30% group showed greater increments in TnT than VL10%. In addition, although no significant differences between experimental groups were observed in resting hormonal concentration, VL30% showed higher percentage increments in different anabolic hormones (GH and IGF-1) than VL10%.
- For load magnitudes of 70%–85% 1RM, and executing each repetition at maximal intended velocity, a curvilinear relationship between percentage VL in the set and changes in strength variables and CMJ performance was observed, with 10% and 20% VL showing greater percentage changes compared with 30% and 40% VL, respectively. A linear relationship was found between changes in T20 and VL in the set.

### Practical applications

The results of the current study will allow us to improve knowledge about the design and quantification of degree of fatigue during RT, as well as to determine the effect of a given training load. Monitoring the VL in the set against the same range of relative loads provides valid, accurate, and objective information for determining the degree of fatigue that will maximize gains in physical performance. As shown in this study, the VL experienced during each training set directly influences functional, neural, and probably structural adaptations. Thus, our results appear to confirm the hypothesis that reaching VL in the set higher than 20% in the SQ exercise produces lower gains in neuromuscular performance. However, the present study also suggests that VL in the set as low as 10% (2–4 repetitions) may be similar to or even more beneficial than higher levels of VL for obtaining increments in physical performance. These findings are of great practical relevance for those athletes aiming to improve their ability to apply force over short time periods without an excessive degree of fatigue that could interfere with other specific technical-tactical skills, and avoiding excessive muscle hypertrophy that could produce an increase in body weight that would negatively affect performance.

### Conflict of interest statement

The authors have no conflict of interest to disclose between any outside institution, company, or manufacture. The results of this study are presented clearly, honestly, and without fabrication, or inappropriate data manipulation.

## Acknowledgements

The authors would like to acknowledge all the volunteers who participated in this study performing the maximum effort in each training session. The authors also greatly appreciate the commitment and dedication of all the graduate and undergraduate students who assisted in data collection.

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