SportRχiv

Part of the Society for Transparency, Openness and Replication in Kinesiology (STORK)

Preprint
not peer reviewed

Accuracy and reliability of perception bar velocity loss as a subjective method for autoregulation in resistance training

For correspondence:
fabiano.fonseca@ufrpe.br

Drumond Gilo da Silva[1], Rodrigo Fabio Bezerra da Silva[1], Petrus Gantois[2], Vitor Bertoli Nascimento[3], Fábio Yuzo Nakamura[4], Fabiano de Souza Fonseca[1,5]

[1] Graduate Program in Physical Education UFPE, Recife, Brazil. [2] Associate Graduate Program in Physical Education UPE/UFPB, João Pessoa, Brazil [3] Department of Physical Education Paraná Federal University, Curitiba, Brazil [4] Research Center in Sports Sciences, Health Sciences, and Hum Development (CIDESD), University of Maia (ISMAI), Maia, Portugal. [5] Federal Rural University of Pernambuco, Recife, Brazil.

Please cite as: Silva, D.G., Silva R.F.B., Gantois P., Bertoli V.N., Nakamura F.Y., Fonseca F.S. (2022). Accuracy and reliability of perception bar velocity loss as a subjective method for autoregulation in resistance training: proof-of-concept. SportRχiv.

ABSTRACT

This study analyzed the accuracy and reliability of the perception of velocity loss as a method to autoregulate the repetitions intra-set using a moderate velocity loss threshold (15-30%). Twenty-two healthy men with resistance training experience (age 28.0 ± 4.3 years, body mass 85.8 ± 8.2 kg) completed a familiarization session to perform exercises with maximal intentional velocity during the concentric phase. After assessing the load-velocity profile in a second session, subjects were familiarized with the perception of velocity loss in a third session. Test-retest procedures were performed in two sessions one week apart, in which participants completed three sets of back-squat and bench press exercises at 40%, 60%, and 80% 1RM. Participants stopped the sets when

All authors have read and approved this version of the manuscript.
This article was last modified on September 27, 2022.

reaching a moderate velocity loss threshold (15-30%) using their perception of velocity loss. A linear encoder recorded the mean propulsive velocity of the bar in all sessions. Accuracy and reliability were assessed through the deviation of mean values and the lower and upper limits of the confidence interval about the pre-established velocity loss range (15-30%). The PVL method showed acceptable accuracy in the test, which improved the retest for both exercises and intensities. For the test-retest reliability, similar values of percentage velocity loss were observed in the comparison between most series during test and retest (p>0.05). These results support the subjective method's accuracy and reliability based on the perception of velocity loss for autoregulation of intra-set repetitions with a moderate velocity loss threshold.

Keywords: velocity-based training, back-squat, bench-press, velocity loss threshold, resistance training.

INTRODUCTION

Neuromuscular adaptations induced by resistance training (RT) programs depend on appropriately manipulating the acute prescription variables such as intensity and volume (8,30,31). Traditionally, the intensity (i.e., load) and volume (i.e., sets and repetitions) of RT have been prescribed in a predetermined and fixed manner over a training cycle (10,14,26). However, this traditional-based approach does not account for daily fluctuation in muscle strength performance related to residual fatigue, muscle damage, fitness level, and training readiness (7,15). It has been shown that assigning the training volume prior to even starting RT sessions could cause a mismatch between the planned and actual training dose experienced by individuals, which may affect both acute and chronic responses (12,21). This potential drawback of the traditional-based approach suggests that strength and conditioning coaches should consider alternative strategies to prescribe training volumes that are more suitable for daily management of RT dose.

Autoregulation of RT is a programming approach that systematically adjusts training prescription variables in response to individuals' perceived readiness to train and/or based on actual individual performance to optimize dose-response stimuli (7,15). Due to the multifaceted and complex nature of training response, it is suggested that RT using different autoregulation strategies may induce greater neuromuscular adaptations compared to traditional predetermined training (2,17,18). In practice, the autoregulation of RT involves the adjustment of load and volume via subjective and objective approaches (7,15). The most common subjective autoregulation method includes applying repetitions in reserve and perceived exertion (RIR-based RPE scale) to adjust load and volume based on proximity to muscle failure (9,11). Notably, it is difficult to gauge the "stop" moment based on RPE when a set is far from intentional muscle failure (i.e., power training sessions). In addition, there is no evidence supporting the effectiveness of the RPE-stop approach on RT adaptations (11). On the other hand, strong evidence has demonstrated that objective quantification of the velocity loss represents a suitable approach to autoregulate intra-set volume due to their strong relationship with indicators related to neuromuscular fatigue (28).

Velocity-based training (VBT) is an approach that allows autoregulation of load and volume in real-time by monitoring movement velocity through valid technology (i.e., linear position transducer) (5,6). During a resistance exercise, by performing every repetition at a maximal effort in the concentric phase, a gradual and unintentional decrease in velocity is observed as fatigue ensues (6,13). Therefore, strength and conditioning coaches can accurately regulate intra-set volume when a specific drop in velocity is achieved (i.e., percentage of velocity loss relative to the fastest repetition) (22,23). It is particularly relevant for designing optimal RT programs since the dose-response relationship between volume and gains in muscle strength may be represented by an inverted "U-shaped" curve (25,27). Therefore, the intra-set volume can be individually autoregulated for different training objectives based on the magnitude of the velocity loss allowed in the set.

A growing number of studies have compared the chronic effects of RT incorporating different VL thresholds (e.g., ranging from 5 to 50%) on neuromuscular adaptations. Overall, it was shown that low (<15%) and moderate VL thresholds (15-30%) resulted in similar gains in muscle strength (3) in a time-efficient manner compared to high intra-set VL (>30%). In addition, low to moderate VL seem to induce greater adaptations in power-related tasks (i.e., sprints and jumps) (22,23,27) than high VL thresholds (>30%). Collectively, these results suggest that a high volume of intra-set repetitions does not induce additional gains in muscle strength and power-related tasks, despite the high levels of discomfort and fatigue experienced during the sets. Therefore, it is suggested that a moderate VL zone (15-30%) may be used as an optimal dose to improve neuromuscular adaptations (i.e., time-efficient and less fatiguing).

In practice, strength and conditioning coaches should consider that using the velocity-based approach might also present some shortcomings. For example, autoregulation of the intra-set VL requires VBT-specific devices such as linear position transducers or accelerometers (1,24). Although the use of many low-cost devices is growing, they may not be accessible to most strength and conditioning coaches (16,33). In addition, using these devices with large groups of practitioners may become impractical (16,33). Therefore, subjective autoregulation methods such as the perception of velocity loss (PVL) can be a practical and affordable alternative when these devices are unavailable. However, empirical studies must investigate its accuracy and reliability to successfully implement the PVL approach in RT programs.

Previous studies have examined the accuracy of perception of bar-velocity in resistance exercises. For example, Sindiani et al. (2020) observed that in resistance-trained individuals, the difference between the velocity change perceived by the participants and the actual changes in bar velocity recorded by a linear encoder, ranged from ~5.8% (2nd repetition) to ~16.7% (8th repetition) in the first experimental session in the bench press and squat exercises (60% 1RM). Subsequently, the absolute error in the second session was reduced by ~1.7% compared to the first session. Of note, the slight improvement in velocity perception accuracy reported by Sindiani et al. (2020) occurred despite the absence of feedback on actual velocity provided to the individuals. Furthermore, Lazarus et al. (2021) found that velocity perception error decreased from ~7.0% to 4.7% following an intervention session with augmented feedback on actual velocity in athletes familiarized with the VBT paradigm. Collectively, these findings suggest that resistance-trained participants demonstrate acceptable levels of accuracy using PVL and that they can improve estimation accuracy with practice and feedback. However, data on the accuracy and reliability of the PVL approach are still limited and need further investigation before implementing it during "real-life" RT programs.

From a practical perspective, applying the PVL as a subjective autoregulation method may be useful for strength and conditioning coaches working with the velocity-based approach to overcome some shortcomings related to the frequent use of VBT-specific devices to implement the velocity-stop paradigm. Therefore, the purpose of the present study was to analyze the accuracy and reliability levels of PVL as a method for autoregulation of intra-set repetitions in a moderate velocity loss threshold (15-30%) following a single intervention session including visual and verbal feedback on actual velocity loss during the bench-press and back-squat exercises at 40%, 60%, and 80% 1RM. We hypothesized that acceptable levels of accuracy and reliability would be found in both exercises at different intensities.

METHOD

Experimental Approach to the Problem

The accuracy and reliability of the RT autoregulation method using PVL were tested in back-squat and bench-press exercises in two identical sessions (test-retest) performed one week apart. The study was conducted in five laboratory visits separated by a minimum of 48 hours. In the first session, participants were familiarized with performing bench-press and back-squat exercises with maximal intentional velocity during the concentric phase. In the second session, participants completed an incremental test to determine the individual load-velocity profile in both exercises. In the third session, we conducted an intervention protocol to use velocity loss perception as a criterion for interrupting intra-set repetitions within a moderate VL threshold zone (15-30%). Participants were instructed and familiarized with a visual scale to identify changes in bar velocity and performed five sets (60% 1RM) for both exercises, and reported their PVL after each repetition. Feedback on the accuracy of their PVL was provided throughout the intervention session. The fourth and fifth sessions were intended for test-retest trials using velocity loss perception to stop when participants felt they were within the range of 15-30% velocity loss threshold. Participants were tested in back-squat and bench-press performing three sets at intensities of 40%, 60%, and 80% 1RM in each session without receiving feedback or any information that would help to estimate the bar velocity. The tests were performed at the same time of day (± 1 hour) under similar environmental conditions.

Subjects

Twenty-two resistance-trained men volunteered to participate in this study (age: 28.0 ± 4.3 years; height: 1.76 ± 0.6 m; body mass: 85.8 ± 8.2 kg; strength training experience: 4.6 ± 1.8 years; bench-press 1RM: 72.3 ± 15.3 kg; back-squat 1RM: 120.8 ± 22.5 kg). Participants 'ages ranged from 18 to 35 years old, were physically active with a training routine with a weekly RT frequency of 4 to 6 times, and did not present any osteoarticular injury. All subjects signed a written informed consent form before participation. The study procedures were conducted according to the Declaration of Helsinki and approved by the University's Ethics Committee.

Procedures

Familiarization - maximum lifting velocity (session 1)

During session 1, subjects were familiarized with performing resistance exercises with maximum intentional velocity during the concentric phase. Subjects started with a general warm-up, which consisted of 5 min of running, 2 x 12 reps of unloaded back-squat, and bench-press. Next, subjects performed a specific warm-up that consisted of 1 x 6 reps at 50% 1RM (estimated) for both exercises. These warm-up procedures were standardized for all sessions of study.

After 3 min passive rest, subjects started familiarization with maximum concentric velocity by performing 4 x 8 reps (60% 1RM estimated) and 4 x 6 reps (80% estimated 1RM) with a 2-3 min rest interval between sets for both exercises. Subjects were encouraged and instructed to perform the concentric phase with maximum intentional velocity. We provided verbal and visual feedback about the bar velocity during familiarization.

Load-velocity relationship and 1RM (session 2)

Following the previously described protocols, a progressive load test was performed to determine 1RM from the individual load-velocity profile. The relative loads of the test sessions were determined from the 1RM estimate obtained by the load-velocity relationship in each exercise. General and specific warm-ups were performed as previously described. The initial load was 20 kg for all subjects, followed by gradual increments of 20 kg until reaching a mean propulsive velocity (MPV) < 0.9 $m.s^{-1}$. Then, the load increments were reduced (15 to 10 kg) until MPV was < 0.50 $m.s^{-1}$. Smaller increments were conducted (6 to 1 kg) until the 1RM could be precisely established. The heaviest load that the subject was able properly to lift without external assistance was considered as his 1RM in each exercise. Three repetitions were performed for light loads (MPV >1.0 $m.s^{-1}$), two repetitions for moderate loads (0.50 $m.s^{-1} \leq$ MPV $\leq$ 1.0 $m.s^{-1}$), and one repetition for heavier loads (MPV < 0.50 $m.s^{-1}$). Inter-set rest ranged from 2 to 3 min for light and moderate loads and 5 min for heavier loads. For the analyses, we considered only the fastest MPV repetition at each load.

Experimental Protocol – PVL to autoregulation (session 3)

One training session intervention was conducted for autoregulation using the PVL, aiming to stop the intra-set repetitions within a zone of moderate VL threshold (15 to 30%). A three colors scale (green, yellow and red) was used as a reference to low VL (< 15%), moderate VL (15-30%), and high VL (> 30%) threshold zones, respectively (Figure 1) (35). Subjects watched the video demonstration twice before each exercise to visually identify changes in bar velocity and VL threshold zones. The video consisted of a set until muscle failure with visual information about bar velocity and VL thresholds. From the second repetition of a set, the VL percentage of that repetition relative to the first repetition was presented after each attempt inside a circle with the equivalent color of VL threshold zones. For example, if repetition 4 was performed with 8%VL in relation to the first one, the value was shown inside a green circle. If repetitions 8 and 11 were performed with 26% and 31% VL, the values were presented inside yellow and red circles, respectively.

Subjects completed a warm-up as previously described, followed by five sets (60% 1RM) for each exercise. They were asked to execute the concentric phase of movement at maximum velocity. Two sets were executed with repetitions to muscle failure with a 5 min inter-sets rest. From the second repetition, subjects verbally reported their PVL using the visual scale after each repetition. Subjects were asked to report their PVL by the colors equivalent to zones with different VL thresholds as presented in the Figure 1 (low < 15% VL = green; moderate 15-30% VL = yellow; high > 30% = red). For example, if the participant perceived a certain repetition presented 10% VL relative to the first one, he would report "green" and so on. Participants received feedback (e.g., right or wrong) after verbalizing the "color" on the scale referring to PVL. When errors occurred in the colors between the perceived and actual velocity loss zone, participants received feedback on the correct color of the scale (35).

After 5 min of rest, subjects completed 3 sets x 60% 1RM whose repetitions are autoregulated by PVL. They were instructed to stop each set within the moderate VL threshold range (15-30%) equivalent to the yellow color of the visual scale. Subjects watched two video demonstrations before each exercise and once between each set (a total of four demonstrations per exercise). Verbal feedback was provided after each set as previously described. Two to three minutes of rest were provided between each set.

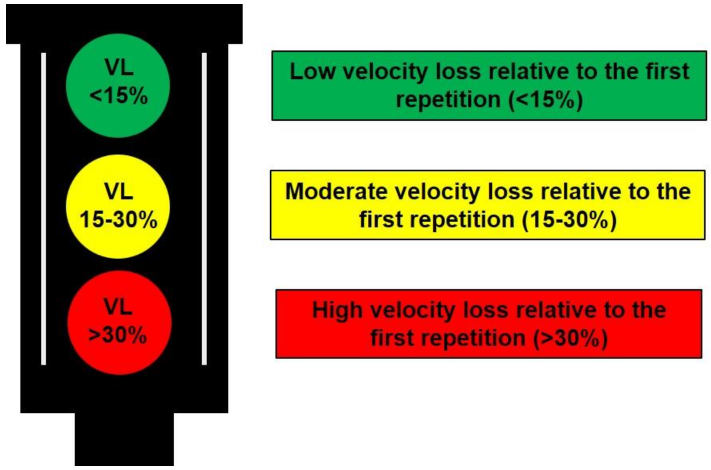

Figure 1. The subjective rating scale for velocity loss threshold zones (adapted from Thorborg et al. (36). The green color indicates a low percentage of velocity loss relative to the first repetition of the set (<15%). The yellow color indicates moderate percentage velocity loss from the first repetition of the set (15 to 30%). The red color represents a high percentage of velocity loss relative to the first repetition of the set (>30%).

Test-Retest of accuracy and reliability (sessions 4 and 5)

The test session was conducted 72 hours after intervention and retested one week after the test. In the test-retest sessions, the subjects executed three sets with different intensities (40%, 60%, and 80% 1RM) in back-squat and bench press using PVL for autoregulation of repetitions. Exercise order and relative loads were randomized among subjects in the test-retest sessions. During the intervention, subjects were instructed to interrupt the set within the moderate VL zone (15-30% VL) equivalent to the yellow color of the visual scale. Test-retest procedures started after warm-up protocols. Subjects did not receive feedback that would help to estimate the bar velocity.

Measurement equipment and data collection

A linear position transducer (Speed4lifts®, Madrid, Spain) was fixed by a cable to the bar at a perpendicular angle to the floor to measure the movement velocity. According to the device specifications, this system measures the cable displacement in response to changes in the bar position at a sampling rate of 100 Hz. The Speed4Lifts® system has shown to be valid and reliable in recording movement velocity with the absolute error below the acceptable maximum error criteria (< 5% 1RM) (24).

The mean propulsive velocity (MPV) of bar movement during the concentric phase was used as the analysis variable. MPV is a derived mechanical variable of the portion of the concentric phase in which the measured acceleration [α] is greater than the acceleration due to gravity ($\alpha \geq -9.81\ m \cdot s^{-2}$) (29).

Lifting technique – bench-press and back-squat

Participants performed bench-press, and back-squat exercises with free weights following protocols described previously (4,29). In the bench-press exercise, subjects were laying supine with their feet flat on the floor. The position on the bench was individually adjusted so that the vertical bar displacement coincided with the projection of the intermammary line. The bar grip was performed with the hands slightly wider than the shoulder line (5-7 cm). Subjects started the execution holding the bar with the elbows fully extended. They were asked to flex their elbows controlling cadence until the bar touched their chest, and after the verbal command, fully extended their upper limbs at the end of lifting.

In back-squat exercise, subjects started standing with knees and hips fully extended, feet positioned approximately shoulder-width apart and slightly outward. The bar was placed on the back at the level of the acromion, in the upper portion of the trapezius muscle. Subjects were asked to hold the bar at the width of the grip normally used in training. After verbal command, participants should flex their knees to ~90° (determined by an elastic band placed parallel to the floor by a tripod), then fully extend their lower limbs at the end of lifting.

All positions and bar grip widths were measured individually and replicated during all study sessions. The eccentric phase of both exercises was executed in a continuous and controlled cadence (2-3 s) with a momentary pause (~1.5 s) before starting the concentric phase (19). Subjects were asked to perform the concentric phase with maximal intended velocity for all lifts. One of the researchers was responsible for controlling the duration of eccentric phase and isometric pauses and providing verbal commands.

Statistical Analyses

Descriptive statistical methods were used to calculate the means and confidence intervals (CI) of the percentage of velocity loss that subjects completed each set of resistance exercises at different intensities (40%, 60%, and 80% 1RM). A Generalized Estimated Equation model (GEE) was used to analyze the accuracy and reliability of the autoregulation based on the PVL method.

Accuracy was assessed inferentially using the deviation from the mean and lower and upper limits of CI (95%) to the moderate VL threshold range (15-30%). Reliability was assessed by comparing mean, CI values between test, and retest sets. Bonferroni's post hoc was used to identify possible differences between the multiple comparisons. The significance level adopted was $p<0.05$. Analyzes were performed using the Statistical Package for the Social Science software (SPSS, IBM Corporation®, New York, USA).

Results

Test-retest accuracy

The mean and CI of velocity loss percentage (%VL) associated with each set interruption in the test and retest in bench-press and back-squat exercises for different intensities are presented in Table 1 and 2, and Figure 2. For the majority of sets during the test in both exercises at three intensities, the mean and CI of %VL were within the range of expected velocity loss equivalent to the moderate VL threshold range (15%-30%) (table 1 and figure 2). In the bench-press exercise with an intensity of 40% 1RM, there was an interruption tendency of sets 2 and 3 with a mean and upper limit of CI %VL within the pre-established autoregulation range (M - 15.6 and 15.2; CI_{upper} -18.0 to 21.1). It was also observed that the mean velocity loss at set 1 and the lower limit of the CI of sets 1, 2, and 3 were below the pre-established autoregulation range (M - 13.8; CI_{lower} - 10.5 to 12.8) (table 1 and figure 2A). At the intensity of 60% 1RM, all sets finished with %VL within the pre-established autoregulation range (M - 17.8% to 21.5%; CI - 15.0% to 25.1%) (table 1 and figure 2B). At the intensity of 80% 1RM, a tendency of interruption of sets 1 and 2 was observed with the mean and lower limit of the CI with %VL within the pre-established autoregulation range (M - 27.2 and 28.0; CI_{lower} - 23.4 to 28.7). However, the mean velocity loss of set 3 and the upper limit of the CI of sets 1, 2, and 3 were above the pre-established range of autoregulation (M - 33.0; CI_{upper} - 31.6 to 38.1) (table 1 and figure 2C).

During the test in back-squat exercise with an intensity of 40% 1 RM (table 1 and figure 2D), there was a tendency of interruption of sets 1, 2, and 3 with a mean and lower limit of CI below the pre-established range of autoregulation (M - 13.8 to 14.4; CI_{lower} - 10.9 to 11.3). The upper limits of CI in sets 1, 2, and 3 were within the pre-established autoregulation range (CI_{upper} - 16.8 to 18.4). On the other hand, with the intensity of 60% 1RM, except for set two, in which the lower limit of CI was slightly below the autoregulation range (CI_{lower} - 14.4), all the sets stopped with a mean and CI of %VL within the pre-established autoregulation range (M - 16.9% to 21.4%; CI - 16.8% to 24.5%) (table 1 and figure 2E). At 80% 1RM, all the sets finished with %VL within the pre-established autoregulation range (M - 21.4% to 25.4%; CI - 18.9% to 28.5%) (table 1 and figure 2F).

Table 1. Mean and confidence interval (95% CI) of velocity loss percentage associated with the interruption of each set in the bench-press and back-squat exercises in test session.

Set	Bench-press			Back-squat		
	40% 1RM	60% 1RM	80% 1RM	40% 1RM	60% 1RM	80% 1RM
1	13.8 [10.5-18.0]	17.8 [15.0-21.2]	27.2 [23.4-31.6]	13.8 [11.0-17.3]	20.1 [16.8-24.0]	21.4 [18.9-24.0]
2	15.6 [12.8-18.8]	19.0 [16.9-21.4]	28.0 [24.1-32.4]	14.4 [11.3-18.4]	16.9 [14.4-19.8]	23.8 [21.1-26.6]
3	15.2 [10.9-21.1]	21.5 [18.4-25.1]	33.0 [28.7-38.1]	13.5 [10.9-16.8]	21.4 [18.7-24.5]	25.4 [22.5-28.5]

During the retest, it was verified that in most sets in both exercises and different intensities, the mean and the confidence interval of %VL were within the range expected to be the moderate VL threshold range (15% to 30%) (table 2 and figure 2). In the bench-press with an intensity of 40% 1RM, the mean and CI of %VL in sets 1, 2, and 3 were within the pre-established autoregulation range (M - 16.2% to 20.7%; CI - 16.0% to 24.5%) (table 2 and figure 2A), except for set 3, in which the lower limit of the CI was below the autoregulation range (CI_{lower} - 13.5). At 60% 1RM, all sets finished with %VL within the pre-established autoregulation range (M - 20.2% to 23.4%; CI - 17.7% to 26.9%) (table 2 and figure 2B). Similarly, at the intensity of 80% of 1 RM, all sets were also finished with a mean and CI of %VL within the pre-established autoregulation range (M – 21.3% to 25.0%; CI – 19.2% to 29.2%) (table 2 and figure 2C).

During the retest of the back-squat exercise at 40% 1RM (Table 2 and Figure 2D), there was a tendency for mean and CI of %VL in sets 1, 2, and 3 to remain within the pre-established VL threshold range (M - 16.3% to 19.3%; CI - 15.5% to 24.0%), except in set 2 whose lower limit of the CI was below the VL threshold range (CI lower - 13.7). At 60% 1RM (table 2 and figure 2E), all the sets finished with a mean and CI of %VL within the pre-established autoregulation range (M – 19.8% to 23.4%; CI – 16.6% to 26.8%). Similar results were found at the intensity corresponding to 80% 1RM. Sets 1, 2, and 3 finished with a mean and CI of %VL within the pre-established VL threshold range (M - 21.4% to 25.4%; CI - 18.92% to 28.5 %) (Table 2 and Figure 2F).

Table 2. Mean and confidence interval (95% CI) of velocity loss percentage associated with the interruption of each set in the bench-press and back-squat exercises in retest session.

Set	Bench-press			Back-squat		
	40% 1RM	60% 1RM	80% 1RM	40% 1RM	60% 1RM	80% 1RM
1	19.0 [16.0-22.4]	20.6 [17.7-23.8]	25.0 [21.5-29.0]	19.3 [15.5-24.0]	19.8 [16.6-23.4]	21.4 [18.9-24.0]
2	20.7 [17.5-24.5]	20.2 [17.7-22.9]	21.3 [19.2-26.1]	16.3 [13.7-19.3]	23.4 [20.4-26.8]	23.8 [21.1-26.6]
3	16.2 [13.5-19.3]	23.5 [20.4-26.9]	24.1 [19.8-29.2]	18.3 [15.4-21.7]	23.1 [20.2-26.4]	25.4 [22.5-28.5]

In general, the results found in the test and retest suggest that the use of the PVL for autoregulation of the level of effort in a moderate VL threshold zone presented a high level of accuracy in both exercises at different intensities. In the test, for example, the accuracy levels were acceptable in both exercises at 40%, 60%, and 80% 1RM. In most of times (74%), the mean and CI of %VL in which the voluntary interruption of the set occurred was within the VL threshold zone equivalent to a moderate level of effort (15-30%). During the retest, the level of accuracy was even higher in both exercises at the three intensities evaluated. Except twice (3.7%), the lower limit of CI was below the limit of the expected autoregulation range (1^{th} set – 40% 1RM for both exercises), in all the other sets (96.3%), the mean and CI of %VL was within the pre-established range of moderate level of effort (15- 30%).

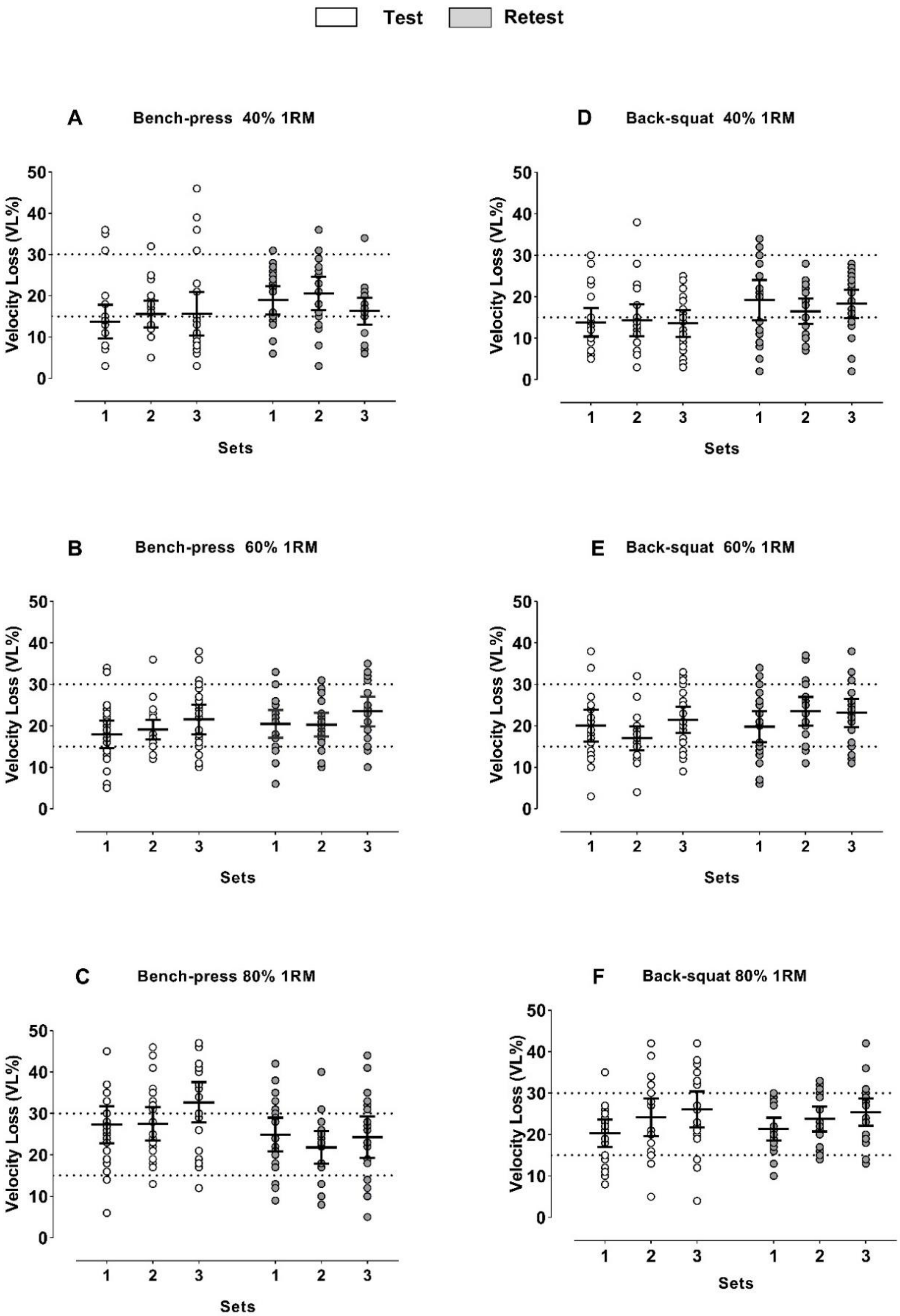

Figure 2 - Accuracy of perception of velocity loss method in the test and retest in the exercises of bench-press and back-squat with different intensities.

Test-retest reliability

The comparison of the mean values and CI of %VL for interruption at the set during the test and retest evidenced high reliability in the bench-press and back-squat completed at different intensities (Figure 3). No significant differences were found between the inter-set comparisons during the test and retest during bench press exercise (Figures 3A, 3B, and 3C) at the intensities of 40% 1RM ($p > 0.12$), 60% 1RM ($p > 0.75$), and 80% 1RM ($p > 0.13$). Similarly, the back-squat exercise (Figures 3D, 3E, and 3F) did not show significant inter-set differences at the intensity of 40% 1RM ($p > 0.13$), sets 1 and 3 at the intensity of 60% 1RM ($p > 0.98$) and sets 1, 2, and 3 at the intensity of 80% 1RM ($p = 1.00$). We found a significant difference only in set 2 of the test and retest at the intensity of 60% 1RM ($p < 0.03$) (Figure 3E).

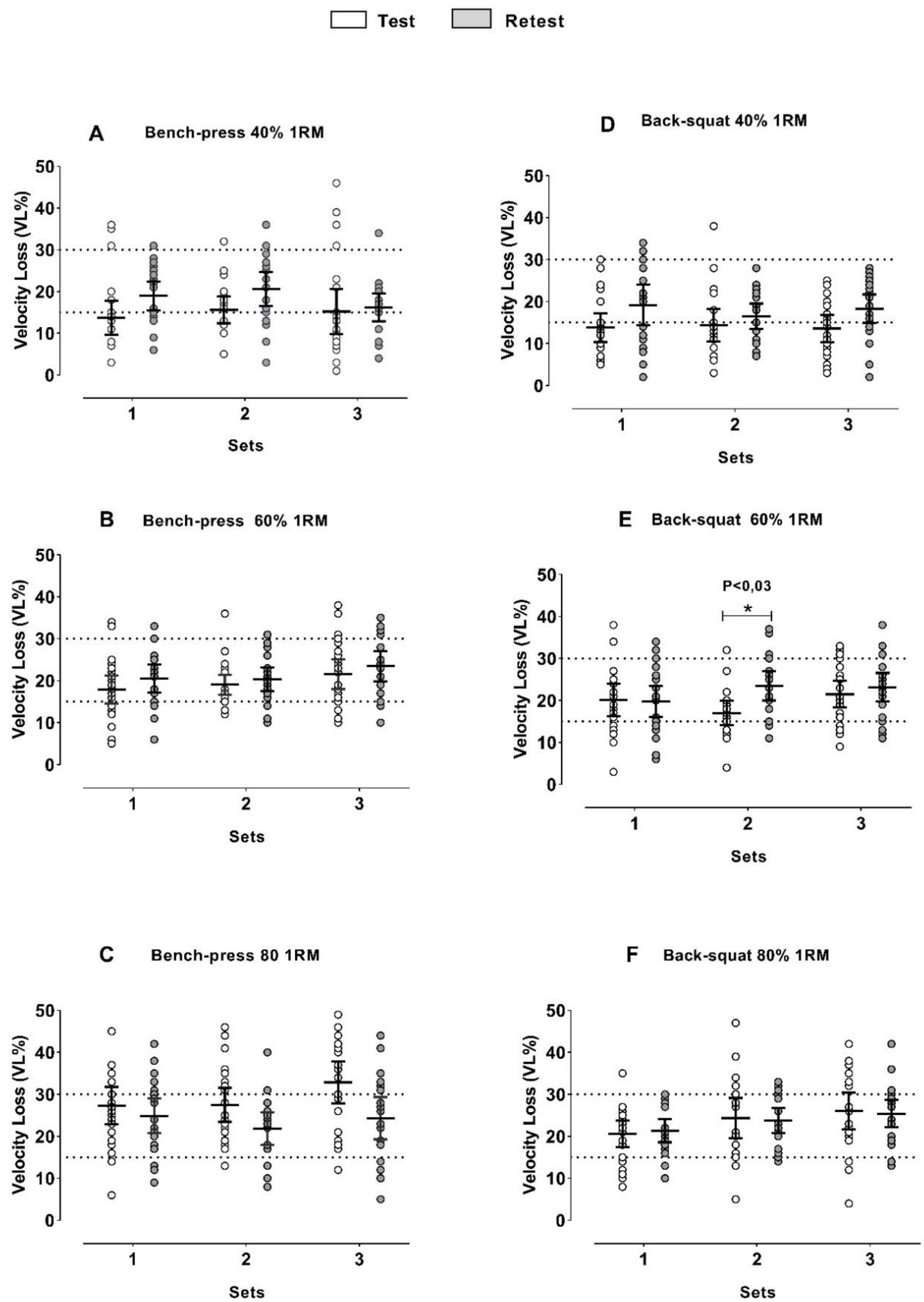

Figure 3 – Reliability of perception of velocity loss in test-retest during bench-press and back-squat exercises with

different intensities.
Note. *Significant difference between test and retest in set 2 ($p<0.03$).

Discussion

The accuracy of PVL during resistance exercises in resistance-trained individuals and athletes has been reported (16,33). However, it is still unclear whether PVL is a subjective method with acceptable levels of accuracy and reliability to be used for autoregulation of intra-set repetitions in a zone of moderate VL threshold (10-30%). The present study is the first to analyze the accuracy and reliability of PVL as a subjective method for autoregulation of the level of effort and intra-set fatigue in bench-press and back-squat at different intensities. Our main findings indicate that: 1) PVL showed acceptable accuracy levels in the first test even after a single intervention session for its application. Moreover, the accuracy was improved when re-tested one week later; 2) very good test-retest reliability was found for autoregulation of intra-set repetitions using PVL; 3) optimal levels of accuracy and reliability of PVL method were observed for bench-press and back-squat at intensities of 40%, 60%, and 80% 1RM.

In the present study, using the PVL for autoregulation of intra-set repetitions within a moderate VL threshold zone showed acceptable levels of accuracy in the test, which improved during the retest. Based on previous findings (16,33), we expected to find a good accuracy level of PVL, especially in the retest. Although previous studies have not directly investigated the accuracy of using PVL for terminating sets at certain VL thresholds, resistance-trained individuals and athletes have demonstrated acceptable levels of accuracy in perceiving changes in bar velocity in bench-press and back-squat exercises performed at 60% 1RM, especially after a period of practice (16,33). Our findings suggest that PVL seems to be a subjective method for autoregulation of intra-set repetitions at moderate VL thresholds with acceptable accuracy for bench-press and back-squat performed with light (40% 1RM), moderate (60% 1RM), and heavy loads (80% 1RM).

Although subjects participated in only one intervention session to learn how to autoregulate intra-set repetitions based on PVL, our findings revealed good test-retest reliability for both exercises at different intensities. A method with excellent reliability presents as characteristics small changes in the mean values observed between tests, small intra-individual variation, and high test-retest reliability (34). From a practical point of view, it is essential to determine the reliability of a new method before applying it in training interventions. We found similar results regarding the percentage of VL at which the sets were finished in the test and retest, under the investigated conditions. It indicates that only one session for familiarization of PVL for autoregulation seems sufficient to achieve optimal reliability to control intra-set repetitions in the VL moderate threshold zone (15-30%). Velocity loss thresholds ranging from 15% to 30% imply a low to moderate level of effort, neuromuscular fatigue, and metabolic stress (28). Training autoregulated by a percentage of VL (i.e., 15% to 30%) induces optimal adaptive responses, even with a volume of intra-set repetitions relatively low (3,21,24,27). The good test-retest reliability that we found indicates that PVL accuracy can be consistent and replicable in different training sessions, which likely makes it feasible to implement this subjective method of autoregulation in training programs. Nevertheless, its effectiveness needs to be tested in longitudinal studies.

The levels of accuracy and reliability of the PVL method were similar between bench-press and back-squat exercises. These results are divergent from previous findings, which showed worse accuracy of PVL in the back-squat when comparing bench-press (35). Methodological differences between the studies can explain divergent results. Sindiani's study did not involve intervention sessions with practice and feedback prior to applying the PVL method. In our study, the familiarization session for using PVL before the tests may have enabled the development of perceptual strategies that allowed improving the accuracy and reliability of results in both exercises to similar levels. Our findings do not support exercise specificities, such as distance of displacement of the bar and duration of propulsive phase, participation of bar's vision during lifting, and amount and size of muscle mass involved as factors capable of affecting the PVL method. However, these are just speculations, as the mechanisms involved in bar velocity perception were not directly evaluated in the present study.

The intensity of resistance exercises caused a small interference in the accuracy of PVL during the first test, but this effect disappeared in the retest. The level of reliability of the test-retest was not influenced by the exercise intensity. Small underestimation errors using PVL occurred in both exercises at 40% 1RM during the test. In contrast, in the bench-press performed at 80% 1RM, small overestimation errors of PVL were observed. These findings can be explained by the inverse relationship between load and velocity (5) and its possible association with the perception of changes in bar velocity, especially when individuals are relatively inexperienced with the application of the PVL method. Light loads (< 40% 1RM) when maximum intentional velocity is applied in the concentric phase typically present high bar velocity when intra-set fatigue is relatively low (i.e., 15-30% PV) (28). Conversely, at heavy loads (> 80% 1RM), the bar moves relatively slowly (28). Accurately identifying velocity reductions when the bar moves at high or slow velocity can be a complex task for resistance-trained individuals with little experience using PVL. In the retest, these small intensity effects on PVL accuracy levels were not evidenced, which reinforces the hypothesis that practice with feedback is important for improving PVL accuracy and reliability. This hypothesis is consistent with previous findings in the literature (16,33).

Several longitudinal studies using objective methods (i.e., linear encoders) to terminate sets at a certain percentage of VL have found that moderate VL thresholds (15-30%) can induce neuromuscular adaptations comparable or superior to high VL thresholds (>30%) (20,22,27). However, monitoring the VL thresholds in real time for autoregulation requires technology devices that may still be inaccessible or impractical for large groups. Subjective autoregulation methods can be a practical and low-cost alternative in these contexts. The efficiency of subjective methods (i.e., perceived exertion and reserve repetitions scales) for autoregulation of intensity and volume of resistance training has been demonstrated in chronic investigations. The efficiency of subjective methods (i.e., perceived exertion and reserve repetitions scales) for autoregulation of intensity and volume of RT has been demonstrated in chronic investigations (9,17,32). The accuracy and reliability data presented here suggest that the subjective method of autoregulation based on PVL may be a viable alternative to apply in resistance training programs as a substitute for velocity monitoring devices used in VBT. However, it is necessary to conduct longitudinal studies to investigate the effects of the PVL method on chronic neuromuscular responses.

Some limitations of this study should be recognized. First, we investigated the accuracy and reliability of the PVL method only in bench-press and back-squat exercises. Resistance training programs are not limited to just two exercises, so it is necessary to investigate this method in other exercises (i.e., deadlift, shoulder press, and bench pull). Second, the study sample was composed only of men with experience in strength training. Therefore, it is necessary to evaluate other populations (e.g., women, youth, and less experienced participants). Third, testing the use of the PVL method in longitudinal resistance training programs is important to assess its efficacy to induce optimal neuromuscular adaptations, but it was not done in the current work.

In conclusion, the results of this study provide evidence supporting the accuracy and reliability of the subjective method based on PVL for autoregulation of intra-set repetitions with a moderate PV threshold (15-30%). This method proved accurate and reliable for bench press and back-squat exercises at intensities of 40%, 60%, and 80% 1RM.

Practical applications

Strength and conditioning coaches currently need technological devices to implement the VBT approach in the objective autoregulation of resistance training. Here, we demonstrate that a subjective method based on PVL can be a viable alternative with good levels of accuracy and reliability for terminating intra-set repetitions within a VL range equivalent to a moderate level of effort and fatigue. A training session with feedback and video demonstrations for the use of this subjective method can be effective for ensuring high accuracy and reliability of PVL in resistance-trained individuals. In summary, our findings suggest the potential application of our simple scale of VL perception as a useful tool to replace technological devices commonly used for autoregulation resistance training.

Contributions

Contributed to conception and design: DG, FSF
Contributed to acquisition of data: DG, FSF
Contributed to analysis and interpretation of data: DG, FSF, VB, FN, RF
Drafted and/or revised the article: DG, FSF, VB, FN, RF
Approved the submitted version for publication: DG, FSF, VB, FN, RF

Acknowledgements

We would like to thank the volunteers and strength-training centers who dedicated themselves to helping make this study possible.

Funding information

No financial support was received for the conduct of this article or for the preparation of this manuscript.

Data and Supplementary Material Accessibility

Data can be made available by request

REFERENCES

1. Banyard HG, Nosaka K, Sato K, Haff GG. Validity of various methods for determining velocity, force, and power in the back squat. *Int J Sports Physiol Perform* 12: 1170–1176, 2017.
2. Colquhoun RJ, Gai CM, Walters J, Brannon AR, Kilpatrick MW, D'Agostino DP, et al. Comparison of powerlifting performance in trained men using traditional and flexible daily undulating periodization. *J Strength Cond Res* 31: 283–291, 2017.
3. Galiano C, Pareja-Blanco F, Mora JH,Villarreal ES. Low-velocity loss induces similar strength gains to moderate-velocity loss during resistance training. *J Strength Cond Res* Publish Ah: 1–6, 2020.
4. Gantois P, Fonseca FS, Nakamura FY, Fortes LS, Fernandez-Fernandez J, Ricarte Batista G. Analysis of velocity- and power-load relationships of the free-weight back-squat and hexagonal bar deadlift exercises. *Biol Sport* 40: 201–208, 2023.
5. González-Badillo J, Marques M, Sánchez-Medina L. The importance of movement velocity as a measure to control resistance training intensity. *Journal Hum Kinet* 29A: 15–19, 2011.
6. González-Badillo JJ, Yañez-García JM, Mora-Custodio R, Rodríguez-Rosell D. Velocity loss as a variable for monitoring resistance exercise. *Int J Sports Med* 38: 217–225, 2017.
7. Greig L, Stephens Hemingway BH, Aspe RR, Cooper K, Comfort P, Swinton PA. Autoregulation in resistance training: addressing the inconsistencies. *Sport Med* 50: 1873–1887, 2020.

8. Grgic J, Schoenfeld BJ. Are the hypertrophic adaptations to high and low-load resistance training muscle fiber type specific? *Front Physiol* 9: 402, 2018.
9. Helms ER, Cross MR, Brown SR, Storey A, Cronin J, Zourdos MC. Rating of perceived exertion as a method of volume autoregulation within a periodized program. *J Strength Cond Res* 32: 1627–1636, 2018.
10. Herrick AB, Stone WJ. The effects of periodization versus progressive resistance exercise on upper and lower body strength in women. J. Strength Cond. Res. 10: 72–76, 1996.
11. Hickmott LM, Chilibeck PD, Shaw KA, Butcher SJ. The effect of load and volume autoregulation on muscular strength and hypertrophy: A systematic review and meta-analysis. *Sport Med - Open* 8: 400–435, 2022.
12. Hughes LJ, Banyard HG, Dempsey AR, Peiffer JJ, Scott BR. Using load-velocity relationships to quantify training-induced fatigue. *J Strength Cond Res* 33: 762–773, 2019.
13. Izquierdo M, González-Badillo JJ, Häkkinen K, Ibáñez J, Kraemer WJ, Altadill A, et al. Effect of loading on unintentional lifting velocity declines during single sets of repetitions to failure during upper and lower extremity muscle actions. *Int J Sports Med* 27: 718–724, 2006.
14. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, et al. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 34: 364–380, 2002.
15. Larsen S, Kristiansen E, Van den Tillaar R. Effects of subjective and objective autoregulation methods for intensity and volume on enhancing maximal strength during resistance-training interventions: A systematic review. *PeerJ* 9, 2021.
16. Lazarus A, Halperin I, Vaknin GJ, Dello Iacono A. Perception of changes in bar velocity as a resistance training monitoring tool for athletes. *Physiol Behav* 231: 113316, 2021.
17. Mann JB, Thyfault JP, Ivey PA, Sayers SP. The effect of autoregulatory progressive resistance exercise vs. linear periodization on strength improvement in college athletes. *J Strength Cond Res* 24: 1718–1723, 2010.
18. McNamara JM, Stearne DJ. Flexible nonlinear periodization in a beginner college weight training class. *J Strength Cond Res* 24: 17–22, 2010.

19. Pallarés JG, Sánchez-Medina L, Pérez CE, De La Cruz-Sánchez E, Mora-Rodriguez R. Imposing a pause between the eccentric and concentric phases increases the reliability of isoinertial strength assessments. *J Sports Sci* 32: 1165–1175, 2014.
20. Pareja-Blanco F, Alcazar J, Sánchez-Valdepeñas J, Cornejo-Daza PJ, Piqueras-Sanchiz F, Mora-Vela R, et al. Velocity loss as a critical variable determining the adaptations to strength training. *Med Sci Sport Exerc* 52: 1752–1762, 2020.
21. Pareja-Blanco F, Rodríguez-Rosell D, Sánchez-Medina L, Gorostiaga E, González-Badillo J. Effect of movement velocity during resistance training on neuromuscular performance. *Int J Sports Med* 35: 916–924, 2014.
22. Pareja-Blanco, F, Rodríguez-Rosell, D, Sánchez-Medina, L, Sanchis-Moysi, J, Dorado C, Mora-Custodio R, et al. Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scand J Med Sci Sports* 27: 724–735, 2017.
23. Pareja-Blanco F, Sánchez-Medina L, Suárez-Arrones L, González-Badillo JJ. Effects of velocity loss during resistance training on performance in professional soccer players. *Int J Sports Physiol Perform* 12: 512–519, 2017.
24. Pérez-Castilla A, Piepoli A, Delgado-García G, Garrido-Blanca G, García-Ramos A. Reliability and concurrent validity of seven commercially available devices for the assessment of movement velocity at different intensities during the bench press. *J Strength Cond Res* 33: 1258–1265, 2019.
25. Peterson MD, Rhea MR, Alvar BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription. *J Strength Cond Res* 19: 950, 2005.
26. Rhea, MR and Alderman, BL. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Res Q Exerc Sport* 75: 413–422, 2004.
27. Rodríguez-Rosell D, Yáñez-García JM, Mora-Custodio R, Pareja-Blanco F, Ravelo-García AG, Ribas-Serna J, et al. Velocity-based resistance training: Impact of velocity loss in the set on neuromuscular performance and hormonal response. *Appl Physiol Nutr Metab* 45: 817–828, 2020.

28. Sánchez-Medina L, González-Badillo JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Med Sci Sport Exerc* 43: 1725–1734, 2011.
29. Sanchez-Medina L, Perez CE, Gonzalez-Badillo JJ. Importance of the propulsive phase in strength assessment. *Int J Sports Med* 31: 123–129, 2010.
30. Schoenfeld BJ, Contreras B, Krieger J, Grgic J, Delcastillo K, Belliard, R, et al. Resistance training volume enhances muscle hypertrophy but not strength in trained men. *Med Sci Sport Exerc* 51: 94–103, 2019.
31. Schoenfeld BJ, Wilson JM, Lowery RP, Krieger JW. Muscular adaptations in low- versus high-load resistance training: A meta-analysis. *Eur J Sport Sci* 16: 1–10, 2016.
32. Shattock K, Tee JC. Autoregulation in resistance training: a comparison of subjective versus objective methods. *J Strength Cond Res* 36: 641–648, 2019.
33. Sindiani M, Lazarus A, Iacono A Dello, Halperin I. Perception of changes in bar velocity in resistance training: Accuracy levels within and between exercises. *Physiol Behav* 224: 113025, 2020.
34. Stöggl T, Lindinger S, Müller E. Reliability and validity of test concepts for the cross-country skiing sprint. *Med Sci Sports Exerc* 38: 586–591, 2006.
35. Thorborg K, Branci S, Nielsen MP, Langelund MT, Hölmich P. Copenhagen five-second squeeze: A valid indicator of sports-related hip and groin function. *Br J Sports Med* 51: 594–599, 2017.