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Comparison of Velocity-Based and Traditional Strength Training Methods on Physiological and Motoric Parameters

Engin Güneş Atabaş[1 *], Ayşegül Yapıcı[2], Gülin Fındıkoğlu Ergin[3], Bilal Utku Alemdaroğlu[2]

[1]Pamukkale University Sports Sciences and Technology Research and Application Center, Denizli, Turkey
[2]Pamukkale University Faculty of Sports Sciences, Denizli, Turkey
[3]Pamukkale University Faculty of Medicine, Denizli, Turkey

*** Corresponding Author**

Engin Güneş Atabaş

Pamukkale University Sports Sciences and Technology Research and Application Center, Denizli, Turkey

e-mail: gatabas@pau.edu.tr

Abstract

Background Traditional resistance training (TRT) often relies on repetitions to failure, which may induce excessive fatigue and impair neuromuscular performance in athletes. Velocity-based training (VBT) offers an alternative by monitoring repetition velocity to prescribe volume. This study compared the effects of VBT with different velocity loss thresholds against TRT on physical performance and muscle adaptations in young soccer players.

Methods Twenty-four young male soccer players (age: 16.25 ± 0.53 years) were randomized into three groups: 10% velocity loss (VL10), 20% velocity loss (VL20), and traditional training to failure (TRD). Over a 6-week period, all groups performed squats, hip thrusts, and deadlifts twice weekly at 80% 1RM. Pre- and post-intervention assessments included 5-10-20 m sprints, countermovement jump (CMJ), zigzag change of direction speed, isokinetic muscle strength, and ultrasonographic muscle thickness.

Results Post-intervention analysis revealed significant improvements in 20 m sprint, CMJ, and muscle thickness (rectus femoris and gluteus maximus) across groups ($p<0.05$). Notably, the VL10 and VL20 groups achieved performance gains similar to or greater than the TRD group but with significantly lower total training volumes. The VL20 group demonstrated the most significant hypertrophic development in the rectus femoris muscle compared to other methods.

Conclusions VBT with low velocity loss thresholds (10-20%) is an effective strategy to enhance explosive strength and hypertrophy while minimizing fatigue accumulation compared to traditional failure training. Specifically, a 20% velocity loss threshold appears optimal for hypertrophy, while 10% is efficient for maintaining power with minimal volume. These methods are recommended for in-season training to manage fatigue while improving athletic performance.

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Keywords Velocity based training, athletic performance, muscle hypertrophy, resistance training, soccer training

Introduction

Soccer is an aerobic-based game in which players typically cover long distances (ranging from 8.6 km to 14.2 km). However, despite covering short distances at high intensity, one of the most critical factors affecting soccer performance and player success is the ability to engage in tackling, jumping, rapid changes of direction, and sprint ability (5, 8, 22) Therefore, soccer coaches emphasize not only the technical skills of the players but also the development of their physical capacities, including muscular strength, speed, and endurance (16). One of the key factors for enhancing players' explosive movement ability is resistance training (RT), which induces various adaptations, including improvements in strength, endurance, power, and hypertrophy. This makes RT a fundamental component of the long-term athletic development process. Designing an effective RT program for athletes requires careful consideration of multiple variables, such as exercise selection and frequency, training load, number of repetitions, overall volume, rest intervals, movement velocity, and the number of sets. Among these variables, training load and volume are considered the most critical factors influencing the nature and extent of both acute and chronic adaptations to RT (12, 23). Traditionally, training load is prescribed as a percentage of one-repetition maximum (%1RM), while resistance training (RT) volume is adjusted by modifying the total number of sets and/or repetitions performed per set. Although this approach is relatively simple and effective, it fails to account for physiological and psychological factors that may influence an individual's day-to-day RT performance, as well as the variability in performance between individuals (24). Determining training load based on %1RM has a significant limitation: it requires either lifting a weight to failure at submaximal loads (direct 1RM estimation) or performing multiple repetitions (indirect 1RM estimation) (3). Research indicates that these methods can impair neuromuscular performance, even in trained athletes, due to the high levels of fatigue they induce (7, 13, 18). A notable issue with traditional strength training is the inconsistency in the relationship between percentage, velocity, and time, as the velocity associated with the planned %1RM can vary during training (18). Another problem is that with the development of technology, traditional methods have difficulty in keeping up with it. Alternatively, determining the pace in a strength training is recommended to adjust the training intensity from the first repetition (6). For this, trainers typically set a specific training load based on an individual's maximal ability (for example, 80% of a max rep). However, athletes are often given a certain number of sets and repetitions (for example, 3 sets of 8 reps) according to their training goals. Velocity-based training (VBT) is a modern approach to resistance training that adapts to variations in individual physical conditions and daily readiness (15). By incorporating VBT, practitioners can precisely establish velocity loss thresholds (e.g., 10%), enabling them to target specific kinetic and kinematic outcomes (10, 18). These thresholds, derived from the peak velocity achieved during the first repetition of a training set, provide guidance on when to conclude a set (18). This method assists practitioners in assessing both velocity decline and the level of neuromuscular fatigue experienced (18). Larger thresholds (e.g., 30% compared to 10%) have been linked to enhanced hypertrophic responses, as they allow for greater training volume before concluding a set (18). Conversely, smaller thresholds (e.g., 10% compared to 30%) are associated with improvements in strength and power, alongside reduced neuromuscular fatigue and a preference for hypertrophy in type II fibers (10, 18). Recent systematic reviews in soccer emphasize that VBT protocols provide real-time feedback that allows for more precise regulation of neuromuscular fatigue compared to traditional methods, which is crucial for maintaining performance during the competitive season (20). Furthermore, VBT has been shown to be superior or equally effective in improving jump and sprint performance while significantly reducing the total training volume (26). Although further studies are still needed on this type of resistance training (VBT), the repetition until failure method implemented in our study has not been used in any previous research. Additionally, the expected range of repetitions that can be completed within a training session has not been detailed. Recent studies have used 10%, 20%, and 30% velocity loss thresholds during VBT prescription (2, 4, 18). The aim of this study was to compare the effects of the traditional RT program in which same loading (80% 1TM), without any VT limit, and the RT program with the same loading (80% 1TM) but different VL limits (10% and 20%), used on changes in strength, physical performance, and ultrasound imaging variables. However, previous studies have not examined hypertrophic development and explosive strength performance of velocity-based strength training and traditional strength training together. The aim of this study was to investigate the effects of three strength training programs that differ in determining the training load on some physiological and motoric characteristics. It was hypothesized that the groups performing velocity loss training would show similar improvements in both explosive strength performance and hypertrophic development similar to the group performing traditional training, however, these improvements would be performed with a much lower volume.

Methods

Study Design

The subjects trained twice a week over a 6-week period, completing a total of 12 sessions. Subjects were randomly assigned to one of three groups based on their relative 1RM: 10% velocity loss (VL10), 20% velocity loss (VL20), or a traditional training group (TRD). To train subjects' strength development, participants performed squats, deadlifts, and hip thrusts on a Smith Machine (Technogym Selection M953 Multipower) (14). Subjects in the VL10 and VL20 groups utilized the PUSHBAR mode of the PushBand device (9) during each training session, employing the concentric mean velocity (CMV) method. In contrast, subjects in the TRD group performed repetitions to failure without the use of any device; sets were terminated when they were no longer able to lift the bar. The experimental design of this study is depicted in Figure 1. All groups, including the velocity-based training groups (VL10 and VL20) and the traditional group (TRD), trained with the same relative load (80% 1RM) throughout the program. The VBT groups controlled their training by monitoring the lifting velocity of the first repetition using PushBand device (Push Inc., Toronto, ON, Canada) device however they differed in the velocity loss threshold reached during each exercise set. PushBand was securely attached to the training bar, and the concentric mean velocity (CMV) values recorded for each lift were transmitted via Bluetooth to a smartphone running the Push application. The subjects' height, body mass, sprint times over 5, 10, and 20 meters (T5, T10, T20), countermovement jump (CMJ) height, zigzag change of direction (COD) speed, ultrasonographic imaging measurements, and isokinetic muscle strength were assessed. Subjects were instructed to abstain from any additional resistance training during the study period. All three groups were tested both before and after the 6-week training intervention. Additionally, all subjects completed a specific warm-up protocol before the field tests. Throughout the intervention period, participants were monitored for any training-related adverse events or injuries by the research team during all training and testing sessions.

One Repetition Maximum Protocol

Subjects completed 1RM testing back squat using methods described previously. Participants performed a standardized warm-up followed by five repetitions at ~50% 1RM, three repetitions at ~70% 1RM, and two repetitions at ~80% 1RM (17). Thereafter, participants performed 1RM attempts with progressively increased loads. Participants were monitored continuously by a member of the research team. To perform squats, participants were instructed to squat with their feet shoulder-width apart until their thighs were parallel to the floor and then return to the starting position. To perform deadlift, participants were instructed to stand with their feet shoulder-width apart, knees bent at 90°, backs straight, and the bar resting on the vertical guide support just below their knees. To perform hip thrust, participants started in a seated position within the designated squat rack with the upper back against a hip thruster bench (smith machine) allowing the inferior angle of the scapula to sit just above it. The hands were instructed to be placed at a comfortable position on the barbell, in a supinated grip, providing the ability for the subject to stabilize the bar while keeping the shoulders in an externally rotated position. A maximum of five attempts were permitted and the last successful lift was taken as the 1RM (17).

Fig. 1 Experimental study design CMJ = countermovement jump; COD = change of direction; RM repetition maximal; wk = week.

Subjects

Twenty-four young male soccer players (Table 1) in the U17 age category volunteered to participate in this study (mean ± SD: VL10, n = 8; age: 16.2 ± 0.5 years; height: 177.7 ±

5.6 cm; body mass: 66.1 ± 6.5 kg; VL20, n = 8; age: 16.5 ± 0.6 years; height: 176.9 ± 4.5 cm; body mass: 67.1 ± 4.4 kg; TRD, n = 8; age: 16.2 ± 0.4 years; height: 177.5 ± 3.1 cm; body mass: 66.8 ± 7.1 kg; soccer training experience: 6.5 ± 0.6 years). All subjects were members of a Turkish first division youth team competing in an elite academy league. They participated in 90-minute training sessions five days per week and played official matches on weekends. All subjects had a minimum of 2 years of weight-training experience as part of their team training program. Only subjects without musculoskeletal injuries or other health issues were included in the study. The initial 1RM strength values were as follows: squat, 149.3 ± 11.4 kg; deadlift, 100.2 ± 5.1 kg; and hip thrust, 185.4 ± 17.8 kg. Only subjects who completed all training sessions were included in the statistical analysis. All subjects and their parents were informed about the research procedures, requirements, potential benefits, and risks before providing written informed consent. The study was conducted in accordance with institutional ethical guidelines for human experimentation and the principles of the Declaration of Helsinki. Sample size was determined based on feasibility and previous studies conducted in elite youth soccer populations using similar training interventions. Given the controlled training environment and the limited availability of elite U17 players within a single competitive team, a total of 24 participants was considered sufficient to detect meaningful within- and between-group changes in performance and muscle-related outcomes, as supported by prior velocity-based training research.

Table 1 Descriptive characteristics of subjects.

Procedures

5-10- and 20-m Sprint Test: The players performed 2 times 5-10-20m sprints. Sprint performance was measured using timing gates (Newtest, Oy, Finland) positioned at 5m., 10m., and 20m from the start line in an outdoor field. There was a recovery period of 3 minutes between the 20m sprints. The shortest time taken to cover the 5-10-20m distance in the sprint test was used in the data analysis.

Vertical Jump Test: After sprint performances, countermovement jump performance was assessed using a small pressure-sensitive contact mat (Smart Speed; Fusion Sport, Brisbane, Australia) in an indoor sports hall. During the testing, the players were asked to keep their hands on their hips to prevent any influence of arm movements on the CMJs and to avoid coordination as a confounding variable in the assessment of the leg extensors. Each player performed 2 maximal CMJs with 30-second recovery time. The players were asked to jump as high as possible; the highest jump was then recorded in centimeters.

Zigzag Change of Direction Speed Test: The zigzag change-of-direction (COD) test was conducted on an outdoor court and consisted of four 5-meter sections (totaling 20 meters of linear distance). The course was marked with cones set at 100° angles, requiring the athletes to decelerate and accelerate as quickly as possible around each cone. Each athlete performed two maximal attempts, with a 5-minute rest interval between attempts. Starting from a standing position, with the front foot placed behind the first pair of timing gates (Smart Speed, Fusion Equipment, Brisbane, Australia) positioned at the starting line, the athletes were instructed to complete the test as quickly as possible. The test ended upon crossing the second pair of timing gates, placed 20 meters from the starting line. The fastest time from the two attempts was recorded for further analysis. To evaluate each athlete's ability to effectively utilize linear speed during a COD task-given that 180° turns are less commonly performed during sport-specific actions in team sports-an adapted COD deficit calculation was employed, as previously described in the literature. The COD deficit was calculated using the following formula: COD deficit = 20m linear velocity - zigzag test velocity

Muscle Ultrasonography: Measurements were performed in the afternoon after participants rested supine for 15 minutes. Muscle thickness was assessed with a B-mode ultrasound (GE Logiq E9, 9-MHz linear probe) using a water-based gel (Aquasonic-100). The probe was positioned at a 90-degree angle with minimal pressure. A trained specialist conducted measurements at these sites: Quadriceps: Midpoint between the anterior superior iliac spine and patella. Gluteus Maximus: Distance from the ischial tuberosity to the skin-fat interface. Gastrocnemius: Thickest point at the proximal one-third of its length. Vastus Intermedius: Midpoint of the anterior thigh beneath the rectus femoris.

Fig. 2 Muscle Ultrasonography Imaging 1 = Rectus femoris ve Vastus Intermedialis muscle thickness; 2 = Gluteus maximus muscle thickness; 3 = Gastrocnemius muscle thickness

Isokinetic Muscle Strength: Lower limb strength was assessed using an isokinetic dynamometer (HUMAC-NORM, Model 770). The protocol included: Quadriceps: Concentric contractions at 60°/s and 180°/s. Hamstrings: Eccentric contractions at 60°/s. Gluteus Maximus: Concentric contractions at 30°/s. Participants performed five trial repetitions with a 1-minute rest, followed by five maximal effort repetitions. The trunk, pelvis, thigh, and tested leg were secured, while the non-tested leg was stabilized. A 3-minute passive rest was provided between sets. The highest peak torques (Nm) from each contraction type were recorded as outcomes.

Statistical Analyses

All data were expressed as mean ± standard deviation (SD). The normality of distribution was verified using the Shapiro-Wilk test ($p<0.05$). Within-group (pre- vs. post-training) comparisons were conducted with paired t-tests, while between-group differences in training effects were examined using a one-way ANOVA. When significant main effects were identified, Bonferroni post hoc tests were applied to determine pairwise differences. Statistical significance was set at $p<0.05$. Effect sizes (ESs) were computed for significant outcomes to estimate the magnitude of differences and were interpreted following the established thresholds for highly trained populations: <0.25 (trivial), 0.25–0.50 (small), 0.50–1.00 (moderate), and >1.00 (large).

This study is reported in accordance with the CONSORT guidelines.

Table 2 Characteristics of the squat, deadlift, and hip-thrust training program performed by each group

Results

Table 3 Comparison of Training Effects

Considering the results of the ANOVA, significant differences in training effects between groups were observed in the 20 m sprint time, countermovement jump height, rectus femoris muscle thickness, and the concentric peak isokinetic force of the knee extensor muscle at angular velocities of 60°/s and 180°/s ($p<0.05$) (Table 3). No significant differences were observed in the 5 m sprint time, 10 m sprint time, zig-zag change of direction time, vastus intermedius, gluteus maximus, and gastrocnemius muscle thicknesses, the concentric peak isokinetic force of the gluteus maximus muscle at an angular velocity of 30°/s, or the eccentric peak isokinetic force of the hamstring muscle at an angular velocity of 60°/s ($p>0.05$) (Table 3).

Table 4 Changes in variables from pre- to post-training for each group

Considering the results of the Paired T-test, positive improvement was observed in the values of all groups except for 5m sprint time in VL10 group, 20m sprint time and zig-zag change of direction speed time in TRD group (Table 4) It was found that the groups performing 10% and 20% velocity loss training showed similar improvements in both explosive force performance and hypertrophic development similar to the group performing traditional training, but they made these improvements with much lower volume.

No training-related adverse events or injuries were reported in any of the groups during the intervention period.

Discussion

Upon reviewing the literature, this study is the first to simultaneously examine explosive strength, muscle strength, and hypertrophic development by comparing velocity-based strength training (VBT) with traditional strength training (TRD). In this study, sprint performance, countermovement jump height, and change of direction time were evaluated as indicators of explosive strength performance. While no significant differences were observed in performance outcomes between the VBT and TRD methods, the VBT method was associated with a lower training volume. Notably, athletes achieved comparable or even greater improvements in performance and development with the VBT method, despite completing fewer repetitions. According to the hypertrophic outcomes of three different training methods, isokinetic strength and ultrasonographic measurements were conducted in this study to evaluate strength and determine changes in muscle hypertrophy. When numerical increases in hypertrophic results were analyzed, it was observed that the VL20 group showed greater improvements in rectus femoris and vastus intermedius muscle thickness compared to the other two groups. The greatest improvement in the gluteus maximus muscle was observed in the VL10 group, while the highest development in the gastrocnemius muscle was found in the TRD group. When comparing training methods between groups, it can be concluded that the VL20 training method is more effective for hypertrophic increases. Differences in muscle hypertrophy after strength training are influenced by various factors, such as training methods, volume, and muscle activation. The hypertrophic differences observed in this study are hypothesized to stem from the potential persistence of sarcoplasmic hypertrophy (an increase in the volume of non-contractile muscle cell fluid, i.e., sarcoplasm).

The VL10 group performed the lowest training volume (number of repetitions: squat = 147.50; deadlift = 137.62; hip thrust = 144.12). The VL20 group completed more repetitions than the VL10 group (number of repetitions: squat = 270.50; deadlift = 232.62; hip thrust = 290.75). The TRD group performed the highest training volume among all groups (number of repetitions: squat = 386.50; deadlift = 303.12; hip thrust = 468.75). According to the results of this study, when planning hypertrophy training, the number of repetitions does not appear to have a linear relationship with the development of hypertrophy. Considering these findings, it can be said that velocity-based strength training is a more effective method for hypertrophy and muscle strength development than traditional methods. In the literature, studies examining hypertrophy and velocity-based strength training in athletes are limited. Pareja-Blanco et al. (19) conducted a study with 22 male athletes who were divided into two groups. The groups trained for 8 weeks using squat movements with 20% and 40% velocity loss. They observed an increase in quadriceps muscle volume in both groups, as assessed via ultrasound imaging. Training with a 40% velocity loss led to greater hypertrophic development in the vastus lateralis and vastus intermedius muscles compared to training with a 20% velocity loss. However, no development was observed in the rectus femoris muscle in either group. In contrast, in our study, greater development in the rectus femoris muscle was observed in the VL20 group compared to the other groups. This result may be attributed to the rectus femoris muscle being predominantly activated during squat, deadlift, and hip thrust movements.

Parpucu (20) divided 60 athletes into two groups (concentric [n=30] and eccentric [n=30]) and evaluated quadriceps femoris muscle architecture, muscle strength, knee proprioception, and functional performance. After 12 weeks of strength training on the dominant leg, similar increases in quadriceps femoris muscle architecture, muscle strength, knee proprioception, and functional performance were observed in both groups. No difference was found in knee concentric force development at an angular velocity of 60°/s, nor in vastus lateralis muscle thickness. The primary function of the rectus femoris muscle is knee extension. In our study, a significant increase in knee concentric force at an angular velocity of 60°/s was observed, with the highest development of the rectus femoris muscle found in the VL20 group. The improvement in isokinetic peak force values in the VL20 group may be due to the hypertrophic development of the rectus femoris muscle, which acts as a key knee extensor. Zaroni et al. (25) conducted an 8-week study with 18 male athletes, dividing them into two groups: one performed split-body training and the other performed total-body training, five days a week. Vastus lateralis muscle thickness was assessed using ultrasound imaging. The total-body group trained with a higher load compared to the split-body group. Despite this, the total-body group showed hypertrophic increases similar to those of the split-body group. In our study, although the TRD group trained with higher volume, the VL10 and VL20 groups demonstrated similar hypertrophic developments with significantly lower training volumes. Based on the results of this study, it can be concluded that the number of repetitions in training does not exhibit a linear relationship with hypertrophic development.

According to the performance outcomes of three different training methods, the number of repetitions in the squat exercise was 147.50 ± 35.6 in the group that trained with a 10% velocity loss, 270.5 ± 45.9 in the group that trained with a 20% velocity loss, and 386.5 ± 58.7 in the group that trained with the traditional method. Additionally, it was found that the group training with a 15% velocity loss performed fewer repetitions (251.2 ± 55.4) than the group training with a 30% velocity loss (414.6 ± 124.9). Despite the lower training volume, the group with a 15% velocity loss showed greater improvements. This finding aligns with a recent meta-analysis by Zhang et al. (26), which confirmed that VBT induces similar strength gains to traditional training but with significantly lower mechanical stress. Moreover, Aloui et al. (1) recently demonstrated that in-season VBT with moderate velocity loss thresholds (e.g., 15%) yielded superior improvements in change of direction and reactive strength index in elite youth soccer players compared to traditional failure training, reinforcing the efficiency of submaximal velocity thresholds for this population. When the literature is reviewed, Pareja-Blanco et al. (19) observed improvements in 30m sprint performance in both groups after 6 weeks of strength training using the average velocity method (CMV) with 15% and 30% velocity losses. Improvements in countermovement jump performance were also seen in both groups, but a significant difference was observed only in the group that trained with a 15% velocity loss, whereas no difference was found in the group that trained with a 30% velocity loss.

In this study, an increase in 10-20m sprint performance was observed in the VL10 and VL20 groups, while a decrease was noted in the TRD group. Countermovement jump values improved in all three groups. This improvement could be attributed to lower fatigue levels or the allowance for strength training at higher velocities. Similarly, Jiménez-Reyes et al. (11) trained 24 male athletes for 8 weeks, dividing them into groups using the daily load adjustment method and the constant load adjustment method. Both groups showed improvements in 10m and 20m sprint performances and countermovement jump performance. However, the constant load adjustment group demonstrated greater improvements in both countermovement jump and 20m sprint performance than the daily load adjustment group. In this study, the groups training with a 10% and 20% velocity loss using the PushBand device showed more significant improvements in 20m sprint and countermovement jump performance compared to the traditional training group. These results suggest that velocity-based strength training is more practical and reliable than the traditional method in evaluating performance outcomes. This study found that three different training methods improved athletes' performance; however, low-volume velocity-based strength training could be an alternative to traditional training methods. It is considered that athletes could utilize VBT training methods, particularly during the competition period.

Practical Applications

Implementing velocity-based strength training (VBT) with low velocity-loss thresholds (≈10–20%) at ~80% 1RM enables coaches to elicit comparable—or in some cases greater—gains in countermovement jump height, 20-m sprint performance, and knee extensor strength than traditional sets to failure, while using markedly fewer total repetitions and incurring less fatigue. Practically, prescribe lower-body lifts (e.g., squat, deadlift, hip thrust) twice weekly over mesocycles of ~6 weeks and terminate each set when concentric mean velocity drops by the pre-set threshold from the first repetition, rather than chasing a fixed rep target or failure. Within this framework, a 20% velocity-loss threshold appears preferable when the goal is hypertrophic adaptation with manageable fatigue, whereas 10% prioritizes strength/power qualities and readiness during congested competition periods. Coaches should consider VBT as an autoregulatory tool; specifically, using velocity loss cut-offs allows for the daily fluctuation of athlete readiness to be accounted for, ensuring that the training stimulus matches the athlete's current physiological state (20). Traditional to-failure work can be reserved for preparatory phases, recognizing its higher fatigue cost and potential to blunt sprint outcomes. Day-to-day load should be adjusted based on the recorded first-rep velocity, and session volume should reflect the efficiency of VBT (expect substantially fewer total reps than traditional prescriptions) to maintain quality of effort and mitigate cumulative fatigue in youth soccer athletes.

Conclusions

For coaches, the velocity-based strength training method offers a unique way to further improve athlete performance. Coaches can achieve similar efficiency from their athletes by training at low velocity losses with a lower total load, as this approach reduces fatigue accumulation and facilitates motor neuronal activity. For athletes, the velocity-based strength training method provides a unique approach that not only motivates them to train but also enhances the overall quality of their training. Considering our study and previous research, it has been determined that low velocity loss thresholds do not induce the necessary physiological and morphological adaptations in athletes. Traditional training performed to exhaustion is observed to reduce training quality due to fatigue, fail to positively impact explosive performance, and may even negatively affect it. However, training with a 20% velocity loss has been found to be more effective in many aspects of development compared to the other two methods, while not inducing fatigue in athletes. Therefore, it is suggested that a 20% velocity loss protocol could be implemented during periods when athletes are exposed to high training loads, particularly during competition phases or times with an increased risk of injury. Furthermore, it is considered that traditional training methods could be utilized during the preparatory phase at the beginning of the season to examine and enhance tendon and ligament development. On the other hand, low velocity loss thresholds (e.g., 10%), which involve lower training volume and create less fatigue, may be applied by coaches during competition periods.

Abbreviations

1RM	One Repetition Maximum
%1RM	Percentage of One Repetition Maximum
ANOVA	Analysis of Variance
CMJ	Countermovement Jump
CMV	Concentric Mean Velocity
COD	Change of Direction
ES	Effect Size
ICC	Intraclass Correlation Coefficient
Nm	Newton-meter
RM	Repetition Maximum
RT	Resistance Training
SD	Standard Deviation
TRD	Traditional Resistance Training
VBT	Velocity-Based Training
VL	Velocity Loss
VL10	10% Velocity Loss
VL20	20% Velocity Loss
wk	Week

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Author contributions

All authors contributed substantially to the conception, design, execution, and interpretation of the study and approved the final version of the manuscript. E.G.A.: conceptualization, methodology, supervision, data curation, formal analysis, writing, original draft, review, and editing. A.Y.: investigation, resources, writing, review and editing. G.F.E.: project administration, critical revision of the manuscript, and final approval. B.U.A.: methodology support, interpretation of results, and writing, review and editing.

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Data availability
All data are within the article.

Declarations

Ethics approval and consent to participate

This study was approved by the Pamukkale University Non-Interventional Clinical Research Ethics Committee (60116787-020-28700). All participants were minors. Written informed consent was obtained from the parents or legal guardians of all participants prior to enrollment, and assent was obtained from the participants themselves.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author Details

[1]Pamukkale University Sports Sciences and Technology Research and Application Center, Denizli, Turkey
[2]Pamukkale University Faculty of Sports Sciences, Denizli, Turkey
[3]Pamukkale University Faculty of Medicine, Denizli, Turkey

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Table 1 Descriptive characteristics of subjects *#

	Height (cm)	Weight (cm)	Body mass (kg)	Training age (y)	Relative squat	Relative deadlift	Relative hip-thrust	1RM squat	1RM deadlift	1RM hip-thrust
VL10 (n = 8) Mean ± SD	16,1 ± 0,6	179,6 ± 8,4	66,8 ± 9,7	6,1 ± 0,6	2,2 ± 0,4	1,5 ± 0,3	2,9 ± 0,5	163,1 ± 20,8	103,7 ± 16,6	193,2 ± 41,5
VL20 (n = 8) Mean ± SD	16,3 ± 0,5	176,5 ± 3,5	66,8 ± 4,3	6,3 ± 0,5	2,1 ± 0,1	1,5 ± 0,1	3,0 ± 0,5	145 ± 10,6	106,2 ± 11,2	201,8 ± 38,3
TRD (n = 8) Mean ± SD	16,2 ± 0,4	177,1 ± 3,8	65,6 ± 4,9	6,2 ± 0,4	2,1 ± 0,4	1,5 ± 0,2	2,9 ± 0,5	150 ± 31,0	100,6 ± 18,2	190,1 ± 29,1

VL10 = group that trained with a mean velocity loss of 10% in each set (n = 8); VL20 = group that trained with a mean velocity loss of 20% in each set (n = 8); TRD = group that trained to failure in each set (n = 8)
* Values are means ± SD.
# Relative strength on squat, deadlift, and hip-thrust presented as one repetition maximum divided by body mass.

Table 2 Characteristics of the squat, deadlift, and hip-thrust training program performed by each group

Scheduled	**Session 1**	**Session 2**	**Session 3**	**Session 4**	**Session 5**	**Session 6**
Sets × Velocity loss (%)						
VL10	3x10%	3x10%	3x10%	3x10%	3x10%	3x10%
VL20	3x20%	3x20%	3x20%	3x20%	3x20%	3x20%
TRD	3xfailure	3xfailure	3xfailure	3xfailure	3xfailure	3xfailure
Squat % 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM
Deadlift % 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM
Hip-thrust % 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM
Scheduled	**Session 7**	**Session 8**	**Session 9**	**Session 10**	**Session 11**	**Session 12**
Sets × Velocity loss (%)						
VL10	3x10%	3x10%	3x10%	3x10%	3x10%	3x10%
VL20	3x20%	3x20%	3x20%	3x20%	3x20%	3x20%
TRD	3xfailure	3xfailure	3xfailure	3xfailure	3xfailure	3xfailure
Squat % 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM
Deadlift % 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM
Hip-thrust % 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM	80% 1RM
Actually performed	**Squat total rep**	**Squat velocity loss (%)**	**Deadlift total rep**	**Deadlift velocity loss (%)**	**Hip-thrust total rep**	**Hip-thrust velocity loss (%)**
VL10	147,5 ± 35,6	14,6 ± 0,0	137,6 ± 15,1	15,1 ± 0,2	144,1 ± 25,5	12,5 ± 0,0
VL20	270,5 ± 45,9	22,7 ± 0,5	232,6 ± 46,6	23,5 ± 0,2	290,7 ± 68,1	24,2 ± 0,0
TRD	386,50 ± 58,7		303,1 ± 20,2		468,7 ± 79,6	

Table 3. Comparison of Training Effects.

	VL10 X̄±Std	VL20 X̄±Std	TRD X̄±Std	F	p	ES
T5 (s)	-0,006±0,025	0,025±0,040	0,018±0,046	1,498	0,247	0,125
T10 (s)	0,018±0,020	0,038±0,040	0,032±0,054	,492	0,618	0,045
T20 (s)	0,061±0,043#	0,038±0,021#	-0,021±0,046	9,774	0,001*	0,482
CMJ (cm)	2,263±1,660	3,371±1,065#	1,425±1,618	3,513	0,048*	0,251
Zigzag COD (s)	0,035±0,111	0,048±0,192	-0,048±0,087	1,174	0,329	0,101
RF thickness (cm)	0,227±0,088	0,317±0,112#	0,167±0,155	3,053	0,049*	0,225
VI thickness (cm)	0,106±0,116	0,155±0,130	0,212±0,123	1,483	0,250	0,124
GMAX thickness (cm)	0,393±0,254	0,315±0,178	0,186±0,101	2,464	0,109	0,190
GASTR thickness (cm)	0,150±0,094	0,148±0,080	0,075±0,080	2,021	0,157	0,161
30°/s GLUT con (N)	40,125±28,970	29,625±11,587	21,000±13,201	1,918	0,172	0,154
60°/s KNEE con (N)	34,875±12,574Ω	59,000±20,283#	21,750±13,498	11,396	0,000*	0,520
60°/s HAMS ecc (N)	60,500±35,160	33,375±59,562	29,875±32,493	1,155	0,334	0,099
180°/s KNEE con (N)	31,625±10,155	38,500±10,433#	18,250±12,747	6,796	0,005*	0,393

ES = effect size between groups; T5 = 5m sprint time; T10 = 10m sprint time; T20 = 20m sprint time; CMJ=countermovement jump height ; Zigzag COD=Zigzag change of direction time; RF=rectus femoris muscle thickness measured by ultrasound imaging; VI=vastus intermedius muscle thickness measured by ultrasound imaging; GMAX=gluteus maximus muscle thickness measured by ultrasound imaging; GASTR=gastrocnemius muscle thickness measured by ultrasound imaging; 30°/s GLUT con = Concentric peak isokinetic force of the gluteus maximus at an angular velocity of 30°/s; 60°/s KNEE con = Concentric peak isokinetic force of the knee at an angular velocity of 60°/s; 60°/s HAMS ecc = Eccentric peak isokinetic force of the hamstring at an angular velocity of 60°/s; 180°/s KNEE con = Concentric peak isokinetic force of the knee at an angular velocity of 180°/s

* Values are mean ± SD. p value indicates significant between group differences. # significant difference from TRD group. μ significant difference from VL10 group. Ω significant difference from VL20 group.

Table 4. Changes in variables from pre- to post-training for each group.

	VL10		VL20		TRD			
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**p-value**	**ES**
T5 (s)	0,931 ± 0,072	0,936 ± 0,059	0,943 ± 0,048	0,918 ± 0,031	0,945 ± 0,053	0,926 ± 0,043	0,247	0,125
T10 (s)	1,615 ± 0,090	1,596 ± 0,082	1,681 ± 0,029	1,642 ± 0,038	1,666 ± 0,082	1,633 ± 0,043	0,618	0,045
T20 (s)	2,815 ± 0,079	2,750 ± 0,062[#]	2,871 ± 0,095	2,830 ± 0,099	2,936 ± 0,115	2,950 ± 0,131	0,001	0,482
CMJ (cm)	38,371 ± 4,137	40,636 ± 3,033[#]	35,816 ± 3,205	39,181 ± 2,535	34,185 ± 4,418	35,618 ± 4,376	0,048	0,251
Zigzag COD (s)	5,235 ± 0,315	5,200 ± 0,224	5,628 ± 0,586	5,580 ± 0,462	5,406 ± 0,390	5,455 ± 0,341	0,329	0,101
RF thickness (cm)	2,416 ± 0,305	2,643 ± 0,298	2,658 ± 0,218	2,976 ± 0,249[µ]	2,473 ± 0,165	2,641 ± 0,184[Ω]	0,049	0,225
VI thickness (cm)	1,647 ± 0,353	1,753 ± 0,280	1,711 ± 0,243	1,866 ± 0,232	1,823 ± 0,319	2,036 ± 0,291	0,250	0,124
GMAX thickness (cm)	3,522 ± 0,285	3,916 ± 0,217	2,923 ± 0,444	3,238 ± 0,420[µ]	3,213 ± 0,747	3,400 ± 0,773	0,109	0,190
GASTR thickness (cm)	1,713 ± 0,209	1,863 ± 0,157	1,740 ± 0,328	1,888 ± 0,321	1,998 ± 0,587	2,073 ± 0,568	0,157	0,161
30°/s GLUT con (N)	165,255 ± 44,803	208,37 ± 51,744[#]	138,000 ± 303,164	167,621 ± 28,040	132,758 ± 53,898	176,584 ± 46,927	0,172	0,154
60°/s KNEE con (N)	190,629 ± 40,184	225,500 ± 40,651	177,624 ± 24,697	236,620 ± 18,543	175,000 ± 268,044	196,755 ± 28,233[Ω]	0,000	0,520
60°/s HAMS ecc (N)	191,120 ± 41,995	251,628 ± 49,888	186,511 ± 36,415	219,870 ± 35,281	189,000 ± 44,715	218,874 ± 46,693	0,334	0,099
180°/s KNEE con (N)	129,870 ± 27,828	161,500 ± 27,925	119,754 ± 45,644	158,255 ± 41,934	110,375 ± 20,895	128,621 ± 15,633	0,005	0,393

ES = effect size between groups; T5 = 5m sprint time; T10 = 10m sprint time; T20 = 20m sprint time; CMJ=countermovement jump height ; Zigzag COD=Zigzag change of direction time; RF=rectus femoris muscle thickness measured by ultrasound imaging; VI=vastus intermedius muscle thickness measured by ultrasound imaging; GMAX=gluteus maximus muscle thickness measured by ultrasound imaging; GASTR=gastrocnemius muscle thickness measured by ultrasound imaging; 30°/s GLUT con = Concentric peak isokinetic force of the gluteus maximus at an angular velocity of 30°/s; 60°/s KNEE con = Concentric peak isokinetic force of the knee at an angular velocity of 60°/s; 60°/s HAMS ecc = Eccentric peak isokinetic force of the hamstring at an angular velocity of 60°/s; 180°/s KNEE con = Concentric peak isokinetic force of the knee at an angular velocity of 180°/s

* Values are mean ± SD. *p* value indicates significant between group differences. # significant difference from TRD group. µ significant difference from VL10 group. Ω significant difference from VL20 group.