©Journal of Sports Science and Medicine (2026) **25,** 838-849
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2026.838

Research article

Effects of 10% Versus 30% Velocity Loss Thresholds on Strength and Explosive Performance in Trained Female Collegiate Athletes: A Randomized Parallel-Group Trial

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Abstract

This study compared the effects of 10% and 30% velocity-loss thresholds during Smith-machine squat training on maximal strength, jumping, and sprint performance in trained female collegiate athletes. Twenty-eight athletes were randomly assigned to a 10% velocity-loss group (VL10) or a 30% velocity-loss group (VL30).Both groups completed 8 weeks of supervised squat training twice weekly, performing four sets at 70% of one-repetition maximum, with each set terminated when the assigned threshold was reached. Smith-machine squat one-repetition maximum (1RM), squat jump (SJ), countermovement jump (CMJ), standing long jump (SLJ), and 30-m sprint (T30) performance were assessed before and after the intervention. Group × time effects were examined using mixed-design analyses of variance. Mean propulsive velocity was higher in VL10, whereas VL30 completed substantially more repetitions per set and per session (all $p < 0.001$). All performance outcomes improved over time (all $p < 0.001$). VL30 produced a greater increase in squat 1RM than VL10 (12.5% vs. 9.2%; interaction $p < 0.001$, $\eta p^2 = 0.450$). VL10 produced greater improvements in SLJ (interaction $p = 0.031$, $\eta p^2 = 0.166$) and T30 time (interaction $p = 0.006$, $\eta p^2 = 0.254$). Group × time interactions were not significant for SJ ($p = 0.127$) or CMJ ($p = 0.058$). Both thresholds improved strength and lower-body performance, but the adaptation pattern differed by outcome. Under the present protocol, VL30 favored 1RM squat strength, whereas VL10 favored SLJ and T30 performance.

Key words: Set termination, mean propulsive velocity, repetition volume, muscle fatigue, squat jump, sprinting.

Introduction

Resistance training induces adaptations across multiple physiological systems, including neural activation, muscle morphology, tendon properties, and intermuscular coordination, with the magnitude and specificity of these adaptations influenced by the characteristics of the training program (Suchomel et al., 2018; Van Hooren et al., 2024). These adaptations range from maximal-strength and hypertrophy development to improvements in power and movement velocity, and their expression differs across performance outcomes (Suchomel et al., 2016; Swinton et al., 2024). Consequently, the manipulation of load, volume, movement velocity, and set termination may influence the pattern of adaptation produced by resistance training.

Velocity-based training (VBT) has emerged as an approach for individualizing resistance-training prescription by using movement velocity to monitor training intensity and fatigue accumulation (Weakley et al., 2021). Within this framework, velocity loss (VL), defined as the percentage decline in repetition velocity from the fastest repetition to the current repetition within a set, provides an objective marker of neuromuscular fatigue and a practical criterion for regulating set termination (Sánchez-Medina and González-Badillo, 2011). Manipulating VL thresholds changes the number and velocity characteristics of the repetitions completed. Lower thresholds prioritize velocity preservation and limit within-set fatigue, whereas higher thresholds permit more repetitions and greater slowing (Jukic et al., 2023a; Weakley et al., 2020). Consequently, VL thresholds should be viewed as set-termination strategies that alter repetition volume and fatigue rather than as isolated percentage values. At the broader programming level, meta-analyses comparing VBT with percentage-based loading have generally reported similar maximal-strength and sprint adaptations, although more recent evidence suggests small advantages for jumping and change-of-direction performance (Orange et al., 2022; Wang et al., 2026).

Accumulating evidence suggests that the magnitude of VL can influence the pattern of resistance-training adaptations. Lower VL thresholds preserve repetition velocity and have generally been associated with more favorable changes in jumping, sprinting, and velocity against submaximal loads, whereas higher thresholds increase the number of repetitions completed and may favor hypertrophy (Jukic et al., 2023a). However, maximal-strength gains are often comparable across thresholds, particularly when repetition volume is more closely matched (Andersen et al., 2024; Myrholt et al., 2023). These findings indicate that the consequences of VL depend not only on the percentage of velocity decline but also on the load, exercise, set configuration, and repetition volume produced by the prescription. A dose-response meta-analysis further identified 15 - 30% VL, 70 - 80% 1RM, three to five sets, and 2 - 4 min inter-set recovery as a generally favorable configuration for improving 1RM strength, although these pooled estimates do not define an optimal threshold for every athlete or exercise (Zhang et al., 2023b).

Received: 01 August 2026 / Accepted: 01 September 2026 / Published (online): 01 December 2026

Importantly, most longitudinal studies of VL-controlled resistance training have involved male participants, while evidence in trained women remains limited (Jukic et al., 2023a). Sex-related differences in skeletal-muscle characteristics and responses to exercise provide a rationale for examining women directly, although the relevance of these differences depends on the task and training prescription (Landen et al., 2023). Rissanen et al.,(2022) directly compared 20% and 40% VL during an 8-week squat and bench-press training program in men and women, assessing 1RM strength, lifting velocity against submaximal loads, CMJ performance, quadriceps muscle activity, and vastus lateralis cross-sectional area. Both VL conditions improved strength, lifting velocity, CMJ performance, and muscle cross-sectional area, with no statistically significant between-threshold differences; however, effect-size patterns in women favored 40% VL for some strength and lifting-velocity outcomes. More recently, Kambara et al.,(2026) compared 10% and 20% VL during 8 weeks of squat training in trained female basketball players and assessed 1RM, SJ, CMJ, and 5-, 10-, and 20-m sprint performance. No significant group × time interactions were observed, although both groups improved 1RM and 10- and 20-m sprint performance, while SJ improved only in the 10% VL group and CMJ showed no clear improvement.

Acute work in women also shows that the relationship between VL and the proportion of available repetitions completed is strong but individually variable (Bachero-Mena et al., 2025). Thus, the available evidence does not establish a uniform female-specific dose-response pattern. Acute comparisons of 20% and 40% VL have also shown greater neuromuscular and metabolic disturbance at the higher threshold, with some pre-training sex differences attenuated after the training period (Walker et al., 2022). In female collegiate basketball players, velocity-based rather than fixed-percentage loading produced similar strength gains but more favorable changes in several jump and change-of-direction outcomes, although that comparison did not isolate the effect of a specific VL threshold (Zhang et al., 2023a). Earlier squat-training research in physically active women likewise showed that the loading configuration influenced the transfer to jump and sprint performance (Mora-Custodio et al., 2016).

Understanding how different VL thresholds influence distinct performance adaptations is particularly relevant for athletes because maximal strength and high-velocity athletic qualities may not respond identically to the same fatigue stimulus. A training strategy that maximizes repetition exposure may benefit strength development, whereas preserving movement velocity may be more advantageous for explosive performance characteristics. However, whether manipulating VL thresholds can produce such divergent adaptation profiles in female athletes has not been fully established.

Accordingly, the purpose of this randomized parallel-group trial was to investigate the effects of 10% and 30% VL thresholds during Smith-machine squat training on strength, jumping, and sprint performance in trained female collegiate athletes. We hypothesized that both VL conditions would improve performance outcomes after training, but that different VL thresholds would produce distinct adaptation patterns, with the lower VL condition providing greater benefits for high-velocity performance measures and the higher VL condition producing greater improvements in maximal strength.

Methods

Study design

This randomized parallel-group trial used a pretest-posttest design to investigate whether different VL thresholds produce distinct adaptations in strength and athletic performance in trained female collegiate athletes (Figure 1). The study consisted of three phases: a 1-week familiarization and baseline assessment period, an 8-week supervised resistance-training intervention, and a 1-week post-intervention assessment period. Participants were randomly assigned in a 1:1 ratio to either a 10% velocity-loss group (VL10) or a 30% velocity-loss group (VL30) using a computer-generated random sequence generated in SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

Training frequency, relative intensity, number of sets, and inter-set recovery duration were standardized between groups. Therefore, the primary experimental manipulation was the VL threshold used to determine set termination, which subsequently influenced the number of repetitions completed and the magnitude of fatigue exposure within each set.

The study protocol was approved by the Ethics Committee of Shandong Sport University (approval no. 2024046) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent before enrollment after receiving detailed information regarding the study procedures, potential risks, and their right to withdraw at any time.

Participants

Twenty-eight resistance-trained female collegiate athletes participated in this study, including six basketball players, five volleyball players, six tennis players, four track and field athletes, and seven rugby players. Participants were eligible if they met the following criteria: (1) ≥ 2 years of structured resistance-training experience; (2) ability to perform a full Smith-machine squat to approximately 90° knee flexion; (3) Smith-machine squat 1RM of at least 1.2 times body mass; and (4) a top-three finish in a provincial-level athletic competition within the previous 12 months.

Participants were excluded if they (1) completed fewer than 80% of scheduled training sessions or (2) sustained an injury during the intervention that could influence performance testing or training participation. According to the participant classification framework of McKay et al.,(2022), the sample was classified as Tier 2 (trained/developmental) (Table 1).

An a priori sample-size calculation was performed using G*Power version 3.1.9.2. Based on a repeated-measures interaction model, the calculation assumed an effect size of f = 0.25, an α level of 0.05, statistical power of 0.80, two groups, two measurement points, an inter-measurement correlation of 0.60, and sphericity correction of ε = 1. The required minimum sample size was 28 participants.

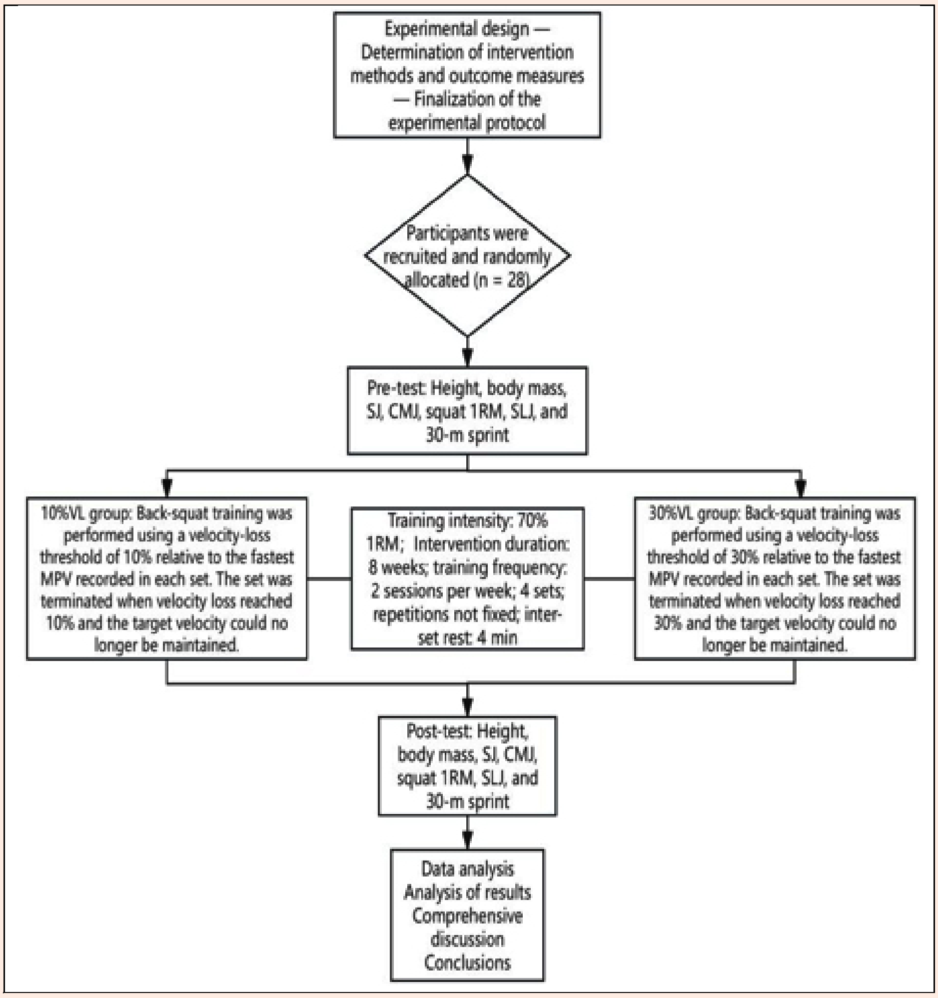

Figure 1. Experimental design and procedures.

Table 1. Participant characteristics

Variables	Group	Mean ± SD	95% CI
Age (years)	VL10	20.43 ± 1.28	19.69 - 21.17
	VL30	20.14 ± 1.23	19.43- 20.85
Height (cm)	VL10	167.86 ± 6.36	164.19- 171.53
	VL30	167.50 ± 7.36	163.25- 171.75
Body mass (kg)	VL10	61.79 ± 11.25	55.29- 68.28
	VL30	63.79 ± 8.40	58.94- 68.63
Smith machine squat 1RM (kg)	VL10	78.9 ± 12.4	71.18- 86.68
	VL30	80.9 ± 11.9	74.29- 87.42
Relative Smith machine squat 1RM	VL10	1.28 ± 0.06	1.24- 1.32
	VL30	1.27 ± 0.05	1.24- 1.30
Resistance training experience (years)	VL10	2.93 ± 0.92	2.40- 3.46
	VL30	2.86 ± 0.77	2.41- 3.30

Experimental procedures

During the week preceding the intervention, participants completed familiarization sessions to standardize testing procedures and movement techniques. Participants were instructed in the correct execution of Smith-machine squats, squat jumps (SJ), countermovement jumps (CMJ), standing long jumps (SLJ), and 30-m sprint (T30) testing.

Participants were instructed to refrain from strenuous exercise for 48 h before each testing session to minimize the potential influence of residual fatigue on performance. They were also instructed to avoid alcohol and caffeine or other stimulants during this period.The first session included anthropometric measurements and Smith-machine squat 1RM testing. The second session assessed vertical jump performance, including SJ and CMJ. The third session included SLJ and T30 testing.

Post-intervention assessments were completed during the week following the final training session using identical procedures. Testing equipment, evaluators, warm-up procedures, movement criteria, verbal encouragement, testing order, and acceptance criteria were standardized across all assessment sessions. Pre- and post-intervention tests for each participant were performed at approximately the same time of day.

Menstrual-cycle phase and hormonal contraceptive use were recorded but were not experimentally controlled.

Outcome Measures

Anthropometric measurements

Standing height and body mass were recorded before baseline testing. Body mass was measured using an InBody 770 body-composition analyzer (InBody Co., Seoul, Republic of Korea). Participants removed their shoes, jewelry, and other external items before measurement.

Squat 1RM and load-velocity profiling

Smith-machine squat 1RM was assessed using a progressive load-velocity protocol (Weakley et al., 2021).Before the progressive load-velocity test, participants completed approximately 10 warm-up squat repetitions, followed by 3 min of rest. The formal progressive loading protocol then began with an external load of 20 - 40 kg. The load was subsequently increased by approximately 10% at each stage.A standardized 3-min passive recovery period was provided between successive loading stages and between 1RM attempts.

Each repetition began from an upright position with the hips and knees fully extended. Participants used a self-selected stance width within standardized technical constraints. In the sagittal plane, the feet were positioned so that the midfoot was approximately aligned with the vertical path of the bar, without deliberate anterior or posterior displacement. This sagittal foot position was maintained because anterior or posterior displacement relative to the fixed bar path can alter hip and knee joint torques during Smith machine squatting (Biscarini et al., 2011). In the frontal plane, the feet were positioned approximately shoulder-width apart or slightly wider, with slight external rotation of the toes permitted. Knee movement was required to remain aligned with the toes throughout the squat.

The target squat depth was established for each participant at approximately 90° between the thigh and lower leg, with the thigh approximately parallel to the floor. A horizontal elastic band was positioned at the corresponding height behind the participant, and participants were instructed to descend until the posterior thigh/gluteal region lightly contacted the band before completing the concentric phase with maximal intended velocity. The same individualized band height was used during subsequent testing, and repetitions that failed to reach the predetermined depth were repeated and not considered valid attempts.

Mean propulsive velocity (MPV) was recorded using a GymAware linear position transducer (Kinetic Performance Technologies, Canberra, Australia). When MPV was greater than 1.15 $m \cdot s^{-1}$, participants completed three repetitions at the corresponding load. When MPV was between 0.70 and 1.15 $m \cdot s^{-1}$, participants completed two repetitions. Once MPV fell below 0.70 $m \cdot s^{-1}$, the external load was increased in 2.5-kg increments until the heaviest load that could be successfully lifted using the required range of motion and technique was identified. A maximum of five 1RM attempts was permitted, consistent with previously reported load-velocity profiling procedures (Banyard et al., 2017). The heaviest successfully completed load was recorded as the Smith-machine squat 1RM.

For each participant, the fastest MPV recorded at each loading stage was paired with the corresponding relative load (%1RM) and entered into Microsoft Excel. An individualized load-velocity profile was constructed by plotting MPV against relative load and fitting a linear regression equation. The resulting individual regression equation was then used to identify the MPV corresponding to 70% 1RM, which served as the target velocity for prescribing the initial training load.

Vertical jump performance

SJ and CMJ heights were assessed using a Just Jump contact mat system (Probotics Inc., Huntsville, AL, USA). For the SJ, participants placed their hands on their hips and descended to an approximately 90° angle between the thigh and lower leg, as determined by visual assessment. They maintained this position until they were visibly stable and then initiated the jump in response to the tester's verbal command. Participants were instructed to jump directly upward without any additional downward movement immediately before take-off.For the CMJ, participants started from an upright standing position, performed a rapid self-selected countermovement, and immediately jumped vertically with maximal effort. Three valid trials were completed for each test, with 60 s of recovery between trials. The maximum jump height achieved across trials was used for analysis.

Standing long jump

Participants stood with both toes behind the starting line, performed a self-paced countermovement with coordinated arm swing, and jumped horizontally as far as possible. Distance was measured from the starting line to the rearmost heel at landing using a calibrated steel tape measure. Three valid trials were completed with 2 min of recovery between trials, and the longest distance was retained for analysis.

Thirty-meter sprint

Sprint performance was assessed over 30 m on a standard outdoor synthetic athletics track. Time was recorded using a Brower TCI wireless infrared timing system (Brower Timing Systems, Draper, UT, USA) with gates positioned at 0 m and 30 m. Participants adopted a standing start with a self-selected lead leg, which was kept consistent between pre- and post-intervention testing. The front foot was positioned 0.5m behind the first timing gate to prevent premature triggering of the timing system. Participants were instructed to sprint maximally through the 30-m finish line without decelerating before crossing the final timing gate. Participants were required to wear the same pair of athletic shoes at each testing session. Two maximal-effort trials were completed with 3 min of recovery between trials, and the faster time was retained for analysis.

Previous research in high-performing athletes has reported good to excellent test-retest reliability for squat 1RM, SJ, CMJ, and 30 m sprint assessments, with ICC values ranging from 0.85 to 0.97 (Lindberg et al., 2022). Acceptable between-day reliability has also been reported for standing long jump performance (Hébert-Losier and

Beaven, 2014).

Training intervention

Participants completed two supervised Smith-machine squat training sessions per week for 8 weeks (16 total sessions). Training sessions were scheduled on Tuesdays and Fridays, providing at least 72 h recovery between sessions. Each session began with a standardized warm-up consisting of 5 min jogging, lower-body and trunk foam rolling, dynamic mobility exercises, and three progressive squat warm-up sets.

Both groups performed four working sets of Smith-machine squats at an intensity corresponding to 70% 1RM, determined from individualized load-velocity profiles. A moderate loading intensity was selected because it allowed sufficient repetitions to achieve different VL thresholds while maintaining practical relevance for athletic resistance training. Inter-set recovery was standardized at 4 min for both groups. At the beginning of each session, the velocity of the first repetition was compared with the individual target velocity. If the observed velocity differed by more than ± 0.04 m·s^{-1} from the target velocity, external load was adjusted accordingly to maintain consistent relative intensity between sessions.

Velocity loss was calculated as the percentage decline in MPV from the fastest repetition to the current repetition within each set using the following equation proposed by Sánchez-Medina and González-Badillo (2011): VL (%) = [(MPVfastest - MPVcurrent)/MPVfastest] × 100.

where MPV fastest is the highest MPV achieved in the set (typically the first repetition) and MPV current is the MPV of the current repetition. MPV was defined as the mean velocity of the concentric phase during which barbell acceleration exceeded acceleration due to gravity ($a > -9.81$ m□s^{-2}). The reference velocity was updated whenever a faster repetition was recorded. The set was terminated when VL reached or exceeded 10% in VL10 or 30% in VL30. Thus, the VL threshold determined the repetitions completed in each set.

Before each set, participants were instructed to complete every concentric phase with maximal intended effort and maximum velocity. Velocity feedback for each repetition was provided in real time via the GymAware system, along with standardized verbal encouragement, to reinforce maximal movement intent throughout each set. No additional lower-body resistance training was permitted during the intervention period. All participants maintained their regular sport-specific technical and conditioning training throughout the intervention period. The intervention was conducted during a general preparation phase of normal training.

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The participant was treated as the unit of analysis. Continuous data are presented as mean ± standard deviation (SD).

Baseline participant characteristics were summarized descriptively. Independent-samples t tests were used to compare training-related variables between VL10 and VL30, including mean MPV, mean number of repetitions completed per set, and mean number of repetitions completed per training session.

Separate 2 × 2 mixed-design analyses of variance were conducted for Smith-machine squat 1RM, SJ height, CMJ height, SLJ distance, and T30 time. Group, comprising VL10 and VL30, was entered as the between-participant factor, and time, comprising pre-intervention and post-intervention measurements, was entered as the within-participant factor. The group × time interaction was the principal effect of interest because it tested whether the magnitude of change differed between the two training conditions.

The normality of model residuals was assessed using the Shapiro-Wilk test, and homogeneity of variance was assessed using Levene's test. ANOVA results were reported as F statistics, exact p values, and partial eta squared (ηp^2). Partial eta-squared values of 0.01, 0.06, and 0.14 were interpreted as small, moderate, and large, respectively (Cohen, 1988). Statistical significance was set a priori at $p < 0.05$.

Results

Training characteristics

Across the 16 training sessions, mean propulsive velocity was higher in VL10 than in VL30 (0.60 ± 0.01 vs. 0.55 ± 0.02 m·s^{-1}; $p < 0.001$). Conversely, VL30 completed more repetitions per set than VL10 (11.17 ± 0.97 vs. 6.29 ± 0.73; $p < 0.001$) and more repetitions per session (44.69 ± 3.89 vs. 25.17 ± 2.94; $p < 0.001$). These data confirm that the prescribed thresholds produced distinct training stimuli: greater velocity preservation in VL10 and substantially greater repetition volume in VL30 (Table 2).

Maximal strength

Both velocity-loss conditions resulted in significant improvements in Smith-machine squat 1RM following the 8-week intervention; however, the magnitude of improvement differed between groups. Squat 1RM increased from 78.9 ± 12.4 kg to 86.2 ± 11.5 kg in the VL10 group (9.2% increase), and from 80.9 ± 11.9 kg to 91.0 ± 12.2 kg in the VL30 group (12.5% increase).

A significant main effect of time was observed for squat 1RM ($p < 0.001$), indicating an overall improvement following training. The main effect of group was not significant ($p = 0.417$). However, a significant group × time interaction was observed ($p < 0.001$, $\eta p^2 = 0.450$), indicating a large differential training effect, with greater improvements in maximal strength observed in the VL30 group (Figure 2).

Table 2. Characteristics of Smith machine squat training.

Variable	VL10 (n = 14)	VL30 (n = 14)	Test statistic	p value
mean propulsive velocity (m • s-1)	0.60 ± 0.01	0.55 ± 0.02	t = 7.410	< 0.001
Mean repetitions per set (n)	6.29 ± 0.73	11.17 ± 0.97	t = -15.005	< 0.001
Mean repetitions per session (n)	25.17 ± 2.94	44.69 ± 3.89	t = -15.005	< 0.001

Data are presented as mean ± SD. MPV, mean propulsive velocity.

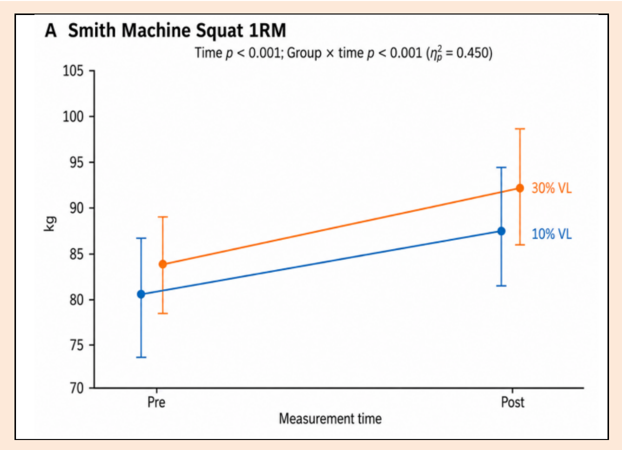

Figure 2. Changes in Smith machine squat 1RM before and after training. Values are estimated marginal means with 95% confidence interval.

Vertical-jump performance

Both groups demonstrated improvements in vertical jump performance following the intervention; however, no significant differences in adaptation patterns were observed between VL conditions. CMJ height increased from 35.1 ± 1.9 cm to 38.6 ± 2.7 cm in the VL10 group (9.76% increase) and from 35.4 ± 2.3 cm to 38.1 ± 2.5 cm in the VL30 group (7.46% increase).

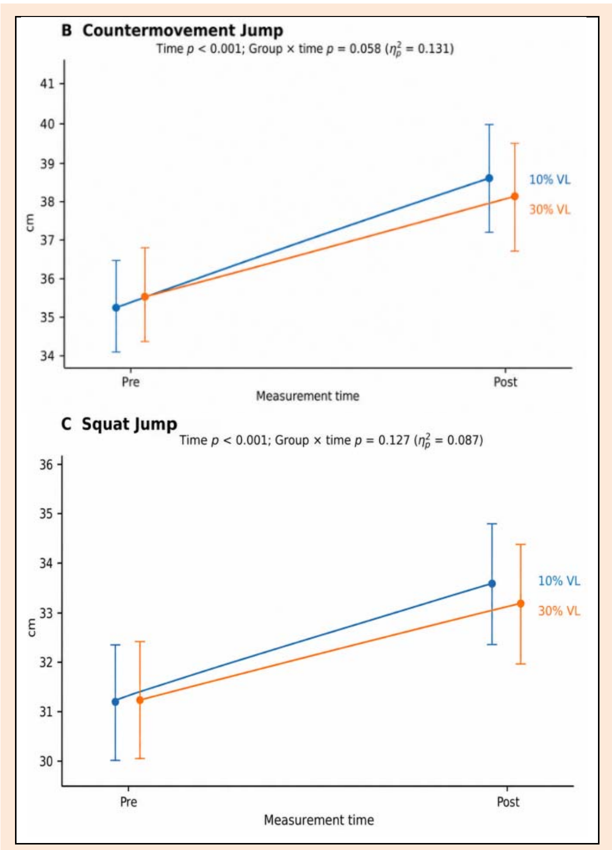

Figure 3. Changes in (B) countermovement-jump and (C) squat-jump height before and after training. Values are estimated marginal means with 95% confidence interval.

A significant main effect of time was observed for CMJ performance ($p < 0.001$). However, the group × time interaction did not reach statistical significance ($p = 0.058$, $\eta p^2 = 0.131$), suggesting that improvements in CMJ height were comparable between the two training conditions.

SJ height increased from 31.1 ± 2.0 cm to 33.6 ± 2.1 cm in the VL10 group (7.80% increase) and from 31.2 ± 2.3 cm to 33.1 ± 2.4 cm in the VL30 group (6.18% increase). A significant main effect of time was observed for SJ performance ($p < 0.001$), whereas the group × time interaction was not significant ($p = 0.127$, $\eta p^2 = 0.087$) (Figure 3).

Horizontal-jump performance

SLJ performance improved following both training interventions, with a greater magnitude of improvement observed in the VL10 group. SLJ distance increased from 195.4 ± 14.0 cm to 201.7 ± 12.8 cm in the VL10 group (3.25% increase) and from 194.7 ± 10.2 cm to 199.6 ± 10.2 cm in the VL30 group (2.49% increase).

A significant main effect of time was observed ($p < 0.001$), indicating improved horizontal jump performance following training. Furthermore, a significant group × time interaction was detected ($p = 0.031$, $\eta p^2 = 0.166$), demonstrating a large differential effect between conditions, with greater improvements observed in VL10 (Figure 4).

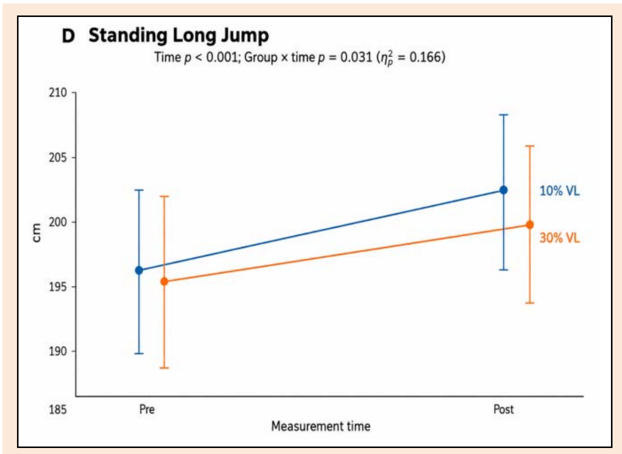

Figure 4. Changes in standing long-jump distance before and after training. Values are estimated marginal means with 95% confidence interval.

Thirty-meter sprint performance

Sprint performance improved following both training conditions; however, the magnitude of improvement was greater in the VL10 group.Thirty-meter sprint time decreased from 5.522 ± 0.208 s to 5.463 ± 0.205 s in the VL10 group (1.07% improvement) and from 5.503 ± 0.170 s to 5.469 ± 0.168 s in the VL30 group (0.61% improvement).

A significant main effect of time was observed for sprint performance ($p < 0.001$). Additionally, a significant group × time interaction was detected ($p = 0.006$, $\eta p^2 = 0.254$), indicating a large differential adaptation favoring VL10 (Figure 5). Changes across all performance outcomes are summarized in Table 3, with the corresponding Hedges' g estimates and 95% confidence intervals shown in Figure 6.

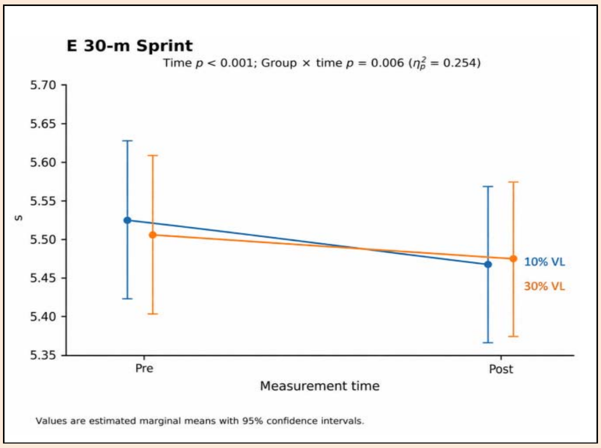

Figure 5. Changes in 30-m sprint time before and after training. Values are estimated marginal means with 95% confidence interval.

Discussion

The present study investigated whether different VL thresholds during Smith-machine squat training produce distinct performance adaptations in trained female collegiate athletes. The main findings were that both 10% and 30% VL conditions improved maximal strength and lower-body performance; however, the pattern of adaptation differed according to the performance outcome examined. Specifically, VL30 produced a greater improvement in Smith-machine squat 1RM, whereas VL10 resulted in greater improvements in SLJ and T30 performance. In contrast, changes in SJ and CMJ performance did not differ significantly between conditions. Collectively, these findings indicate that VL thresholds should not be interpreted as universally superior or inferior, but rather as strategies that distribute velocity preservation and repetition accumulation differently within a set.

Table 3. Changes in selected athletic performance variables from pre- to post-training for each group.

Variable	VL10 (n = 14)		VL30 (n = 14)		Change		p-value	Hedges' g (95% CI)
	Pre	Post	Pre	Post	VL10	VL30		
Smith machine squat 1RM (kg)	78.9 ± 12.4	86.2 ± 11.5	80.9 ± 11.9	91.0 ± 12.2	9.2%	12.54%	0.001	-0.23 (-0.35-to 0.10)
Squat jump height (cm)	31.1 ± 2.0	33.6 ± 2.1	31.2 ± 2.3	33.1 ± 2.4	7.80%	6.18%	0.127	+0.23 (-0.07 to +0.52)
Countermovement jump height (cm)	35.1 ± 1.9	38.6 ± 2.7	35.4 ± 2.3	38.1 ± 2.5	9.76%	7.46%	0.058	+0.37 (+0.01 +0.75)
Standing long jump distance (cm)	195.4 ± 14.0	201.7 ± 12.7	194.7 ± 10.2	199.6 ± 10.2	3.25%	2.49%	0.031	+0.12 (+0.01 to +0.23)
30-m sprint time (s)	5.522 ± 0.208	5.463 ± 0.205	5.503 ± 0.170	5.469 ± 0.168	1.07%	0.61%	0.006	+0.13 (+0.04 to +0.22)

Values are mean±SD. Percentage changes indicate improvements and were calculated as [(post−pre)/pre] × 100, except for 30-m sprint time, for which [(pre − post)/pre] ×100 was used. The reported p values refer to the group×time interaction from the 2×2 mixed-design ANOVA. Hedges'g represents the standardized between-group difference in pre-to-post change using the pooled baseline SD; positive values favor VL10 and negative values favor VL30. 1RM, one-repetition maximum; CI, confidence interval; VL10, 10% velocity-loss group; VL30, 30% velocity-loss group.

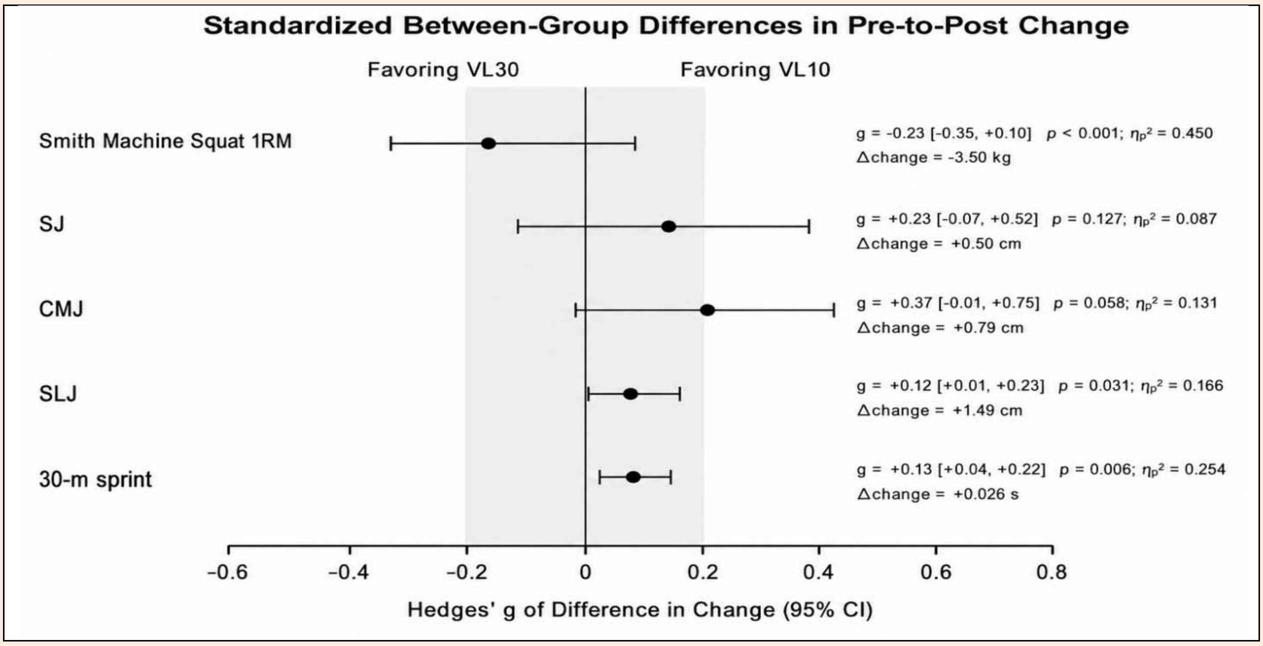

Figure 6. Standardized between-group differences in pre-to-post changes in Smith machine squat one-repetition maximum (1RM), squat jump (SJ), countermovement jump (CMJ), standing long jump (SLJ), and 30-m sprint (T30) time. Points represent Hedges' g, and horizontal bars represent 95% confidence intervals. Effect sizes were calculated for the between-group differences in change and standardized using the pooled baseline standard deviation. VL10, 10% velocity-loss group (n = 14); VL30, 30% velocity-loss group (n = 14). Positive values favor VL10, whereas negative values favor VL30. The shaded area denotes trivial effects (|g| < 0.20).

The actual training exposure is central to this interpretation. Although relative load, training frequency, number of sets, and interset recovery were standardized, VL10 maintained a higher mean propulsive velocity than VL30, whereas VL30 permitted substantially more repetitions per set and per session. Thus, the groups did not differ only in an abstract percentage of velocity decline. VL10 represented a prescription with greater velocity preservation and lower repetition volume, whereas VL30 extended each set further into the velocity decline and accumulated almost twice as many repetitions. Increasing VL is known to alter repetition number, mean velocity, level of effort, acute fatigue, and recovery requirements (Cornejo-Daza et al., 2024; Jukic et al., 2023a; Rodríguez-Rosell et al., 2020; Sánchez-Medina and González-Badillo, 2011; Weakley et al., 2020; 2024). A nominal VL percentage therefore has limited meaning unless the repetitions and velocity characteristics it produces are also reported.

The number of repetitions completed before reaching a nominal threshold also depends partly on how VL is calculated. García-Ramos et al.,(2021) showed that the repetitions completed before reaching a threshold differ according to the reference repetition and velocity variable used. The present protocol used the fastest repetition recorded within the set as the reference and MPV as the velocity variable. García-Ramos et al.,(2021)compared mean and peak velocity and recommended the fastest repetition rather than the first repetition as the reference. Differences in the selected velocity variable and reference repetition should therefore be considered when comparing the current findings with studies using other operational definitions. Both groups received identical real-time velocity feedback, which may have helped maintain maximal intended concentric velocity throughout training (Weakley et al., 2023). Because feedback was provided in both conditions, however, it cannot account for the differential adaptations observed between VL10 and VL30.

The greater increase in squat 1RM after VL30 is notable because it differs from the broader tendency in the existing literature. Longitudinal comparisons have frequently shown that prescriptions using low or moderate VL thresholds can produce gains in maximal strength similar to those obtained with higher thresholds despite requiring fewer repetitions (Galiano et al., 2022; Pareja-Blanco et al., 2020; Sánchez-Moreno et al., 2020). Studies in which repetition volume was more closely matched have likewise reported similar adaptations in maximal strength across conditions using lower and higher VL thresholds (Myrholt et al., 2023; Andersen et al., 2024). At the level of evidence synthesis, VL appears to exert a relatively limited influence on maximal strength development, whereas higher thresholds are more consistently associated with hypertrophic adaptations and lower thresholds with more favorable responses in jumping and sprinting performance (Jukic et al., 2023a). A meta-analysis identified VL thresholds of 15% to 30% combined with loads of 70% to 80% 1RM as a favorable configuration for 1RM development (Zhang et al., 2023b). A recent large factorial trial in men with resistance training experience also showed that the strength response depended jointly on relative intensity and VL, with 25% VL producing the largest gains in bench press 1RM and 50% VL favoring hypertrophy (Pareja-Blanco et al., 2026). These findings reinforce that the effect of VL cannot be separated from the load, exercise, and outcome being considered.

Participant sex is one contextual difference between the present study and much of the existing literature. Most longitudinal comparisons of VL thresholds have been conducted in male samples, whereas the limited evidence in women has not revealed a consistent dose-response pattern. Rissanen et al.,(2022) observed similar group-level improvements after 20% and 40% VL, with some effect-size patterns favoring 40% VL in women, whereas Kambara et al.,(2026) found no significant between-group differences after 10% and 20% VL. The current result extends this limited evidence, but methodological differences in relative load, threshold contrast, repetition volume, training status, and exercise selection remain important when comparing studies. In the present protocol, the difference between approximately six and eleven repetitions per set provides the most direct basis for interpreting the divergent 1RM responses.

The current finding does not indicate that greater within-set fatigue is inherently beneficial for maximal-strength development. A more defensible interpretation is that the effectiveness of a low threshold depends on whether the number of repetitions it permits is sufficient for the prescribed load, exercise, set configuration, and athlete population. Under the present 70% 1RM protocol, terminating sets at 10% VL limited participants to approximately six repetitions per set, whereas VL30 permitted approximately eleven repetitions. Although VL10 provided a sufficient stimulus to improve squat 1RM, the additional squat repetitions completed under VL30 may have supported a greater improvement in the trained exercise. This explanation is particularly relevant because both the intervention and strength test involved the Smith-machine squat, increasing the potential contribution of repeated practice of the tested movement (Stone et al., 2024).

The result is compatible with evidence that dose-response relationships differ across performance outcomes and are not necessarily linear (Jukic et al., 2023a; Swinton et al., 2024). A relatively low repetition volume may produce meaningful strength gains without maximizing adaptation under every training configuration, whereas progressively extending sets does not guarantee progressively larger gains. The present design cannot determine whether the greater VL30 response resulted primarily from the additional repetitions, greater exposure to slower repetitions, a higher level of effort, or their combined influence. Muscle hypertrophy, neural activation, motor-unit behavior, and metabolic stress were not assessed and therefore cannot be identified as the mechanisms underlying the difference.

The absence of clear between-group differences in SJ and CMJ limits any interpretation that VL10 produced a generalized advantage in explosive performance. Although both tests require rapid lower-limb force production, they differ in movement organization. SJ performance depends predominantly on concentric impulse generation from a relatively static starting position, whereas CMJ additionally involves the eccentric and braking phases, countermovement strategy, muscle-tendon interaction, and the transition into propulsion (Van Hooren and Zolotarjova, 2017). The lack of differential change in either vertical-jump test indicates that preserving repetition velocity did not confer a clearly greater benefit than accumulating additional repetitions for these specific outcomes.

However, nonsignificant interactions should not be interpreted as evidence that the two prescriptions produced physiologically equivalent adaptations. Jump height alone cannot reveal possible differences in braking impulse, propulsion duration, countermovement depth, take-off velocity, or joint-level contributions (Anicic et al., 2023). Given that the CMJ interaction approached the conventional significance threshold and showed a moderate effect size ($p = 0.058$; $\eta p^2 = 0.131$), the absence of statistical significance should be interpreted as insufficient evidence of a between-group difference rather than evidence that the two prescriptions were equivalent. The present findings therefore indicate that a differential effect on the measured vertical-jump outcomes was not established.

A different pattern was observed for SLJ, which showed a between-group response favoring VL10. The different responses of the horizontal and vertical jump tests further indicate that jump performance should not be treated as a single adaptation domain. Although all three tests require rapid lower-limb force production, their task constraints differ. SJ and CMJ are primarily vertical projection tasks, whereas SLJ requires the effective conversion of take-off velocity into horizontal displacement. Accordingly, the SLJ response cannot be generalized to vertical jumping or interpreted as evidence of a broad improvement in lower-body power.

By terminating sets before substantial velocity decline, VL10 preserved a higher average MPV and reduced the number of slower repetitions. This characteristic may have been more compatible with the rapid whole-body projection required during horizontal jumping than the greater repetition volume completed under VL30. Horizontal jump performance is also moderately to strongly associated with sprint acceleration and maximal-speed performance, although such associations do not establish a common mechanism (Lin et al., 2023). The present study did not assess horizontal impulse, take-off angle, joint kinetics, or movement coordination. The result therefore demonstrates a difference in SLJ adaptation but does not identify the biomechanical or neuromuscular process responsible for that difference.

The T30 findings extend this outcome-specific pattern. VL10 produced a greater improvement in sprint performance despite eliciting a smaller increase in squat 1RM. This dissociation indicates that a greater improvement in maximal force capacity did not automatically result in greater transfer to a rapid athletic task. Maximal strength represents an important foundation for sprint performance (Suchomel et al., 2016; 2018), but transfer also depends on the time available to apply force, movement velocity, intermuscular coordination, and the correspondence between the training and target tasks (Hughes et al., 2023; Makaruk et al., 2024; Van Hooren et al., 2024). The higher average MPV maintained under VL10 may have increased the compatibility of the resistance-training stimulus with the rapid force-expression demands of sprinting. This interpretation concerns task specificity rather than demonstrating changes in neural drive, rate of force development, horizontal force production, or sprint mechanics, none of which was measured.

Previous evidence concerning VL and sprint adaptation remains inconsistent. Some interventions have reported more favorable sprint changes with lower VL thresholds (Rodríguez-Rosell et al., 2021; Rojas-Jaramillo et al., 2024), whereas others have found no clear between-threshold differences (Kambara et al., 2026; Pareja-Blanco et al., 2017). The systematic review by Jukic et al.,(2023a) indicates that lower VL is generally favorable for sprint adaptation, but also highlights substantial heterogeneity related to exercise selection, load, threshold contrast, training status, and intervention design. These factors may explain why the available findings are not uniform.

The present result is particularly relevant because the condition producing the greater sprint improvement was not the condition producing the greater squat-strength improvement. Together with the SLJ response, this finding indicates that transfer from VL-based squat training depended on the performance task. However, the SLJ and sprint results should not be assumed to reflect the same mechanical adaptation merely because both tasks involve horizontal displacement. Because only total T30 time was recorded, it is not possible to determine whether the greater VL10 response occurred during the initial acceleration phase, later acceleration, or the approach to maximal velocity. Sprint split times and force-velocity assessments would be required to locate the specific component of sprint performance that changed.

Taken together, the findings support conceptualizing a VL threshold as a rule that determines where a set is terminated and how repetitions are distributed across different levels of velocity decline. Lower thresholds emphasize repetitions performed while velocity is relatively preserved, whereas higher thresholds permit additional repetitions after a larger reduction in performance. The adaptive relevance of this distinction depends on relative load, exercise selection, total set number, threshold calculation, athlete characteristics, concurrent training demands, and the outcome being targeted (Jukic et al., 2023a; 2023b). This interpretation is more appropriate than assigning VL10 and VL30 to rigid 'speed' and 'strength' categories. A nominal VL percentage has limited explanatory and comparative value unless the repetitions and velocity characteristics produced by that threshold are also reported.

From an applied perspective, VL selection should reflect both the targeted adaptation and the repetition volume that can be accommodated within the wider program. Under conditions comparable with the present intervention, VL30 may be considered when improving Smith-machine squat 1RM is the immediate priority and the athlete can accommodate the additional repetitions. VL10 may be considered when maintaining repetition velocity, limiting lower-body resistance-training volume, and supporting sprint-related adaptation are important. The SLJ finding may also be relevant when horizontal jump performance is of interest, although replication is needed before it forms the basis of a strong prescription. From a periodization perspective, rather than applying one threshold throughout the training year, VL may be adjusted according to the objective of the training phase, exercise selection, and concurrent sport demands (Jukic et al., 2023a; Tundidor-Duque et al., 2026; Van Hooren et al., 2024).

Several limitations should be acknowledged. Although participants were not permitted to undertake additional resistance training for the lower body, they continued their regular technical and conditioning training for their respective sports. These activities were not experimentally standardized and may have contributed to variability in training adaptation. Sprint testing was conducted on an outdoor synthetic track. Although the testing procedures were standardized, environmental conditions such as wind and temperature were not formally recorded or controlled and may have introduced additional measurement variability. The sample also included athletes from multiple sports, and general physical performance outcomes rather than measures of performance specific to each sport were assessed, limiting direct transfer to competition. Menstrual cycle phase, hormonal contraceptive use, sleep, and energy availability were not systematically controlled.

Conclusion

After 8 weeks of Smith-machine squat training, both the 10% and 30% VL protocols were associated with improvements in maximal strength and lower-limb performance in trained female collegiate athletes. VL30 produced a greater improvement in squat 1RM, whereas VL10 produced greater improvements in SLJ and T30 performance than VL30. These findings support selecting VL thresholds according to the intended adaptation. Under conditions similar to those used in the present study, VL30 may be considered when improving Smith machine squat 1RM is the primary objective and the additional repetition volume can be accommodated, whereas VL10 may be preferable when preserving movement velocity and supporting horizontal jump or sprint performance are priorities. The results should not be interpreted as evidence that 10% VL is universally optimal, because the threshold also altered repetition volume and fatigue exposure.

Acknowledgements

No funding was received for this work. The data sets generated during this study are not publicly available because of the confidentiality of the data, but are available from the corresponding author on reasonable request. Heartfelt thanks to all subjects who volunteered to participate in this study. The experiment complies with the current laws of the country where it is conducted. The authors declare that they have no conflict of interest. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscript.

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Key points

- Eight weeks of Smith-machine squat training with either 10% or 30% velocity-loss (VL) thresholds produced significant improvements in squat strength, jumping and sprint performance among resistance-trained female collegiate athletes, but the two protocols triggered task-specific adaptive differences.
- The 30% VL group achieved greater gains in maximal squat strength, whereas the 10% VL group showed greater improvements in SLJ and T30 performance; changes in vertical jump performance did not differ significantly between the two groups.
- Practitioners should choose VL thresholds according to periodized training targets: 30% VL is recommended for maximal lower-body strength development, whereas 10% VL is more suitable for optimizing horizontal explosive power and sprint performance in female athletes.

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