

Research article

Mechanical Output and Post-exercise Jump Responses to Percentage-Based, Repetitions-in-Reserve, and Velocity-Based Back-Squat Training in Trained Sprinters: A Randomized Crossover Study

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Abstract

The purpose of this study was to compare acute mechanical output and immediate post-exercise jump responses among percentage-based training (PBT), repetitions in reserve (RIR), and velocity-based training (VBT) during the back-squat exercise in trained sprinters. Eighteen trained male 100-m sprinters completed all three conditions in randomized order using a within-participant crossover design, with at least 72 h between trials. Each condition began at 80% of one-repetition maximum and comprised of five sets with a maximum of five repetitions per set. Bilateral force plates recorded vertical ground-reaction force during squatting and during pre- and post-exercise countermovement jump (CMJ) and squat jump (SJ) tests. Completed repetitions averaged 25.00, 25.00, and 24.06 per session under PBT, RIR, and VBT, respectively; session volume loads also differed among protocols. No statistically significant overall condition effects were detected for relative peak vertical force ($p = 0.348$), mean positive vertical impulse ($p = 0.262$), CMJ jump height ($p = 0.969$), CMJ modified reactive strength index ($p = 0.894$), or SJ jump height ($p = 0.740$). The present study found that VBT resulted in fewer completed repetitions and lower session volume load than PBT and RIR. No significant between-protocol differences were detected in session-level mechanical output or immediate postexercise jump responses.

Key words: Autoregulation, neuromuscular fatigue, force plate, strength and conditioning, explosive performance, training load.

Introduction

Resistance training is a key means of developing lower-body strength and power in sprinters (Smirniotou et al., 2008). However, it must also be integrated within the broader sprint-training program: the training stimulus should be sufficient while avoiding an undue reduction in the quality of subsequent sprint, jump, or event-specific technical work. Greater within-set velocity loss is typically accompanied by higher blood lactate accumulation, impaired jump performance, and greater neuromuscular fatigue (Sánchez-Medina and González-Badillo, 2011). Accordingly, maintaining mechanical output while controlling acute fatigue through appropriate load regulation is an important consideration in resistance training for sprinters.

Percentage-based training (PBT), in which loads are prescribed relative to the one-repetition maximum (1RM), is widely used to regulate resistance-training load. This approach facilitates the advance planning of load, sets, and repetitions and supports standardized programming. However, a single 1RM assessment may not reflect an athlete's day-to-day capacity. Even at the same percentage of 1RM, the maximum number of repetitions that can be completed may differ substantially among athletes with different training backgrounds (Richens and Cleather, 2014). Consequently, the same relative load and prescribed repetition count may represent different proximities to task failure. Velocity-based training (VBT) and repetitions in reserve (RIR) provide two alternative approaches to autoregulation. VBT regulates training volume according to movement velocity and its decline (González-Badillo and Sánchez-Medina, 2010), whereas RIR requires athletes to estimate how many additional technically acceptable repetitions they could complete at the end of a set (Zourdos et al., 2016). Velocity loss and RIR are associated during the back squat (Rodríguez-Rosell et al., 2020), indicating that both approaches may provide information about remaining repetition capacity. Whether they produce different training responses depends on whether the feedback meaningfully alters load, repetition number, or within-set effort.

Autoregulation research often overlooks a critical issue: different regulation methods do not necessarily produce different training exposures. PBT protocols may specify a fixed repetition target, RIR-based protocols may specify a target repetition reserve, and VBT protocols may combine a velocity-loss threshold with a repetition cap. When repetitions per set are restricted, the permitted within-set exposure and resulting acute mechanical output may converge across approaches. Banyard et al., (2019) used a back-squat protocol of 80% 1RM, five sets, and no more than five repetitions per set. Velocity-based regulation altered selected velocity and session-organization characteristics, but most kinetic and power outcomes did not differ. Cowley et al., (2025) directly compared PBT, rating of perceived exertion (RPE), RIR, and VBT and likewise found no evidence that autoregulation reduced postexercise neuromuscular fatigue or muscle soreness. These findings suggest that monitoring information can

confer an acute advantage only when it is translated into a meaningful adjustment of the training stimulus. Meta-analytic evidence also indicates that average differences between VBT and PBT in maximal strength, power, and sprint adaptations are small and remain uncertain (Liao et al., 2021; Orange et al., 2022).

Direct evidence in sprinters remains limited. In a 6-week intervention, both VBT and PBT improved squat strength, jump performance, and 20-m sprint performance. VBT produced greater gains in maximal strength and selected velocity outcomes, whereas changes in the counter-movement jump (CMJ) and standing long jump were similar between groups (Guo et al., 2026). This pattern suggests that the long-term benefits of VBT may arise through the accumulation of repeated training exposures rather than through a smaller functional decrement after every session. For sprint practice, a more immediate question is whether the three strategies produce different mechanical stimuli within a single training session and whether any such differences influence postexercise lower-body explosive performance.

Most acute studies evaluate differences among training approaches using barbell velocity, completed repetitions, and ratings of perceived exertion. These measures do not fully characterize the mechanical interaction between the athlete and the ground. Barbell velocity can serve as the control signal in VBT, but it cannot substitute for vertical force or impulse. Similarly, jump height alone may not fully characterize postexercise changes in jump mechanics. Force-time analysis of the CMJ and squat jump (SJ) can provide complementary information on power and impulse characteristics (Gathercole et al., 2015; Hughes et al., 2022). Integrating mechanical output during training with postexercise jump responses therefore provides a more direct assessment of whether different load-regulation strategies alter the acute training stimulus. The purpose of this study was to compare session-level mechanical output during back-squat training and immediate postexercise jump responses among PBT, RIR, and VBT protocols in trained male sprinters. We hypothesized that RIR and VBT would maintain mechanical output more effectively and attenuate immediate postexercise decrements in jump performance compared with PBT, while producing similar acute responses to one another.

Methods

Study Design

A randomized, within-participant crossover design was used to compare three back-squat conditions: PBT, RIR, and VBT. All 18 participants completed all three experimental conditions. The order of the three conditions was randomized before experimental testing using a drawing-lots procedure. The 1RM test was separated from the first experimental trial by at least 48 h, and consecutive experimental trials were separated by at least 72 h to minimize residual fatigue from the preceding condition.

Participants

Eighteen male 100-m sprinters were recruited. The inclusion criteria were as follows: (1) classification as a Chinese

national second-class athlete or higher; (2) systematic sprint training and regular resistance-training experience; (3) familiarity with the free-weight back squat and the ability to complete the exercise with standardized technique to the required depth, defined as the position at which the hip and knee joints were at the same horizontal level; (4) ability to complete all three training conditions and associated tests; and (5) voluntary participation with written informed consent. Exclusion criteria were (1) a lower-extremity musculoskeletal injury within the previous 12 months that affected training or testing; (2) pain, restricted joint range of motion, or another functional limitation affecting squatting or jumping; and (3) a known cardiovascular, metabolic, or neurologic disorder. All 18 participants (age = 20.0 ± 1.3 years, height = 181.17 ± 4.60 cm, body mass = 74.38 ± 6.50 kg, back-squat 1RM = 150.0 ± 21.3 kg, relative back-squat 1RM = 1.97 ± 0.40 kg·kg⁻¹, systematic resistance-training experience = 2.40 ± 1.24 years, and 100-m performance = 11.03 ± 0.14 s) met the inclusion criteria and completed the PBT, RIR, and VBT conditions. For the present report, a sensitivity power analysis was conducted to characterize the detectable omnibus effect size for the completed repeated-measures design. With 18 participants, three repeated conditions, an alpha level of 0.05, an assumed correlation of 0.50 among repeated measures, and a nonsphericity correction of epsilon = 1.0, the design provided 80% power to detect an omnibus effect of approximately Cohen's $f = 0.31$. Before participation, all athletes received an explanation of the study purpose, experimental procedures, potential risks, and right to withdraw and provided written informed consent. The study was approved by the Sports Science Experimental Ethics Committee of Beijing Sport University (approval no. 2026358H) and was conducted in accordance with the principles of the Declaration of Helsinki.

Procedures

Pretrial standardization and familiarization

Before the experimental trials, participants completed a standardized familiarization session that covered back-squat technique, use of the RIR scale, the VBT termination rule, and the CMJ and SJ procedures. During RIR familiarization, participants practiced estimating the number of additional technically acceptable repetitions they could complete at the end of a set. The investigators emphasized that RIR reflected remaining repetition capacity rather than pain or general perceived exertion. During the 72 h before each trial, participants refrained from strenuous or prolonged physical activity and from additional lower-body resistance training; they refrained from eating during the 1 h before testing. Participants were instructed to maintain similar dietary intake, habitual training, and test preparation across trials. The same research team conducted all trials and standardized squat technique instructions and verbal encouragement.

Back-squat one-repetition maximum testing

Before the crossover trials, participants completed a free-weight back-squat 1RM test. The barbell was positioned across the posterior deltoids, with the feet slightly wider

than shoulder width and the toes slightly externally rotated. Squat depth was defined as the position at which the hip and knee joints were at the same horizontal level. This criterion was visually monitored in real time by the research staff during both the 1RM test and all experimental back-squat sessions. A repetition was considered valid only when this depth criterion was met and the concentric phase was completed without external assistance. Participants first performed 5 - 10 repetitions at an estimated 50% 1RM and rested for 1 min. The initial load estimate was based on each participant's previous training records and self-reported habitual back-squat loads rather than a prediction equation. The load was then increased progressively according to the outcome of the preceding attempt. Larger increments, typically 10 - 20 kg or approximately 10%-20%, were used during the earlier stages to approach the expected 1RM efficiently, whereas smaller adjustments were used as the participant approached maximal loading. Following a failed attempt, the load was reduced by 5 - 10 kg or approximately 5%-10% before retesting. The 1RM was typically established within 3 - 5 maximal-load attempts. The initial load for each training condition was set at 80% 1RM, and at least 48 h of recovery separated the 1RM test from the first training condition.

Countermovement- and squat-jump testing

The same two Kistler 9286BA force plates and BioWare 5.4.8.0 acquisition software described above were used for CMJ and SJ testing. Raw force-time data were exported from BioWare and processed offline in Python using laboratory-developed scripts. Before and after each training condition, participants completed three CMJ and three SJ trials, always in that order. Each foot was positioned on a separate force plate. Foot position was kept consistent across all tests, and participants performed all CMJ and SJ trials with their hands on their hips. The CMJ began from a quiet standing position. Participants used a self-selected countermovement depth, performed a rapid reversal, and jumped vertically with maximal effort. The SJ began from a stable semisquat position, and participants were familiarized with the starting position during the familiarization session and instructed to reproduce it consistently across trials. A trial was flagged for countermovement contamination if the force-time or velocity-time curve indicated a preliminary downward movement. Participants were required to remain stable before takeoff and to land with both feet within the force-plate area. Force-plate data were sampled at 1000 Hz. After the left- and right-side vertical forces were summed, the primary signal was low-pass filtered using a fourth-order, zero-lag Butterworth filter with a 20-Hz cutoff. Movement onset was identified when the vertical ground-reaction force deviated from the standing-force level by an adaptive threshold defined as the greater of 3.5% of standing force, five times the baseline force standard deviation, or 20 N, sustained for at least 20 ms. Takeoff was identified when total vertical force fell below 20 N for at least 20 ms, and landing was identified when force subsequently exceeded 20 N for at least 20 ms. Standing force was estimated as the median vertical ground-reaction force over the 180-ms window from 200 to 20 ms before detected movement onset. Participant mass was

estimated by dividing this standing-force value by gravitational acceleration. Net center-of-mass acceleration was calculated by subtracting body weight from total vertical force and dividing the result by body mass. Vertical center-of-mass velocity was obtained by numerical integration of the acceleration-time signal, and vertical displacement was obtained by a second integration. Jump height was calculated primarily using the impulse-momentum method; the flight-time method was used only for quality control (Xu et al., 2023). For the SJ, trials were screened for countermovement contamination using the force-time and derived velocity-time curves. A preliminary downward movement before the intended upward propulsion was considered countermovement contamination. The CMJ braking phase began when vertical center-of-mass velocity reached its minimum and ended when velocity returned to 0 m/s. The propulsive phase began when vertical center-of-mass velocity became positive and ended at takeoff, consistent with the phase convention described by McMahon et al., (2018). For the SJ, the propulsive phase began with the initiation of upward movement from the static squat position and ended at takeoff. Phase identification followed established force-time analysis frameworks (Chavda et al., 2018; McMahon et al., 2018). The primary jump outcomes were CMJ jump height and the modified reactive strength index (RSI_{mod}). RSI_{mod} was calculated as jump height divided by time to takeoff, where jump height was derived using the impulse-momentum method and time to takeoff was defined as the interval from detected movement onset to takeoff. Relative peak positive power, relative mean propulsive power, relative propulsive impulse, and the corresponding SJ jump-height and force-time variables were treated as secondary outcomes.

Power was calculated as the product of total vertical ground-reaction force and vertical center-of-mass velocity. Peak positive power was defined as the maximum instantaneous power during the propulsive phase, whereas mean propulsive power was calculated as the average instantaneous power over the same phase. Propulsive impulse was calculated by integrating net vertical force, defined as total vertical ground-reaction force minus body weight, over the propulsive phase using the trapezoidal rule. Peak and mean power and propulsive impulse were normalized to body mass. For each condition, time point, and jump type, the arithmetic mean of all valid trials was used. Trials with minor quality-control warnings were retained when the primary events could still be identified reliably; trials were excluded when takeoff, landing, the stable baseline, or jump type could not be identified with confidence.

Experimental trials

Each experimental trial followed the same sequence. Participants first completed a 10-min dynamic warm-up, followed by three back-squat repetitions at each of 20%, 40%, and 60% 1RM and one warm-up repetition at 80% 1RM. All warm-up repetitions were performed with maximal intended concentric velocity. After 2 min of rest, participants completed the preexercise CMJ and SJ tests in that order and then began the assigned back-squat condition.

Each condition comprised five sets of free-weight back squats, with 2 min of rest between sets and

Table 1. Protocols for the three training conditions

Condition	Initial prescription	Within-set criterion	Load-regulation procedure
PBT	80% 1RM; 5 sets	5 repetitions per set	Load, number of sets, and repetitions were not adjusted according to subjective readiness or movement velocity.
RIR	80% 1RM; 5 sets	Up to 5 repetitions per set; target = 3 RIR	RIR was reported after each set. The next-set load was reduced by 5 kg when RIR was < 3, increased by 5 kg when RIR was > 3, and left unchanged when RIR was 3.
VBT	80% 1RM; 5 sets	20% decrease in mean concentric velocity or completion of 5 repetitions	Set termination was determined from real-time mean concentric velocity; training load remained unchanged.

Abbreviations: 1RM, one-repetition maximum; PBT, percentage-based training; RIR, repetitions in reserve; VBT, velocity-based training.

approximately 2 s between consecutive repetitions within a set. Participants performed the eccentric phase at a self-selected but controlled tempo; no fixed eccentric duration was imposed. They were instructed to avoid an uncontrolled rapid descent and, on reaching the required depth, to immediately initiate the concentric phase with maximal intent. Technique instructions and verbal encouragement were standardized across conditions. No additional recovery period was provided after the fifth set; participants began the postexercise CMJ immediately after completing the final squat set. After the CMJ trials, a standardized 45-s recovery period was provided before the SJ trials. The protocols for the three conditions are summarized in Table 1. The external load and actual number of completed repetitions were recorded for each set. Session volume load was calculated as the sum of external load multiplied by completed repetitions across the five sets.

During VBT, a Tendo Unit linear position transducer (Power Analyzer-W, Tendo Sports Machines, Slovakia) was used to monitor mean concentric barbell velocity. The Tendo tether was secured to the right sleeve of the barbell, and this attachment position was kept consistent for all participants and experimental sessions. Before each set, the position of the Tendo unit was adjusted so that the tether was as close to vertical as possible when the participant was standing upright with the barbell. Tether alignment was visually checked by an investigator before each set and monitored during the exercise; if obvious lateral deviation occurred, the trial was paused and the device position was readjusted before testing continued. A set was terminated when mean concentric velocity had decreased by 20% relative to the reference velocity for that set; if this threshold was not reached, the set ended after five repetitions. Participants could not view the numerical velocity values, thereby minimizing the potential influence of visual feedback on movement intent and training performance. Thus, the RIR protocol used perceived repetitions in reserve to adjust the load for the subsequent set, whereas the VBT protocol maintained a constant load and used velocity loss to determine set termination.

Force-plate assessment during back-squat training

Two Kistler 9286BA force plates (Kistler Instrumente AG, Switzerland) synchronously recorded bilateral vertical ground-reaction forces, with one foot positioned on each plate. Signals were sampled at 1000 Hz using BioWare 5.4.8.0 software. Raw force-time data were exported from BioWare as text files and processed offline in Python using laboratory-developed scripts. The exported left- and right-side vertical-force signals were summed to obtain total vertical ground-reaction force. The summed signal was then

low-pass filtered using a fourth-order, zero-lag Butterworth filter with a 20-Hz cutoff for the primary mechanical variables. Before each set, participants stood still on the force plates for 1 - 2 s while holding the external load prescribed for that set. The software recorded the mean vertical ground-reaction force during this period as the set-specific calibration force of the athlete-barbell system ("Normalized force (N)") in the corresponding force-plate file. A new calibration force was obtained for each set, including when the external load was adjusted between sets in the RIR condition. Individual force-time cycles were identified from the periodic force-time signal using a peak-based segmentation procedure. Similar repetition-level analysis of continuous force-time recordings has been used to quantify peak force during multi-repetition back-squat exercise (Staheli et al., 2024). Candidate peaks were required to be separated by at least 1.5 s, exceed 103% of the set-specific calibration force, and have a local prominence of at least 8% of the calibration force. Boundaries between adjacent cycles were defined as the midpoint between successive detected peaks; the first and final cycle boundaries were positioned approximately 0.75 s before the first detected peak and 0.75 s after the final detected peak, respectively. Mean repetition duration was operationally defined as the duration of the resulting segmented cycle. Thus, the training force-time analysis represented the complete segmented squat cycle rather than separately identified unweighting, braking, and propulsion phases. The primary mechanical outcomes during training were relative peak vertical force and mean positive vertical impulse. Relative peak vertical force was calculated for each valid segmented cycle as the maximum total vertical ground-reaction force observed within the complete segmented cycle, divided by the calibration force recorded for its corresponding set. Values were expressed as multiples of system weight and averaged across all valid cycles within the trial. For positive vertical impulse, net vertical force was calculated as total vertical ground-reaction force minus the corresponding set-specific calibration force. For each segmented cycle, positive vertical impulse was calculated as $J_{\text{positive}} = \int_{t_1}^{t_2} \max [F_z(t) - F_{\text{cal}}, 0] dt$, where $F_z(t)$ represents total vertical ground-reaction force, F_{cal} represents the set-specific calibration force and t_1 and t_2 denote the boundaries of the segmented squat cycle. Numerical integration was performed using the trapezoidal rule over the complete segmented cycle. Consequently, all positive portions of the net-force signal within a cycle contributed to the impulse, whereas negative net-force values were set to zero and therefore did not reduce the calculated positive impulse. Mean positive vertical impulse was calculated as the

average of the cycle-level impulse values across all valid segmented cycles within the trial. Secondary outcomes were mean repetition duration and peak-force and impulse maintenance from set 1 to set 5. Set-by-set trajectories were treated as exploratory outcomes.

Heart-Rate Monitoring

The Polar H10 chest strap was fitted before the standardized warm-up and worn throughout the experimental trial. The electrode areas of the strap were moistened with water before placement, and no conductive gel was used. The strap was positioned directly against the skin around the chest, and participants wore a training shirt over the device during exercise. Heart rate was recorded continuously at approximately 1-s intervals. Heart-rate recordings were matched to the corresponding force-plate records by participant, condition, and test time, and maximum heart rates were calculated from the point-by-point data.

Statistical Analyses

Continuous variables are presented as mean $\pm$ standard deviation, together with estimated between-condition differences and 95% confidence intervals. All tests were two-sided, with alpha set at 0.05. Statistical analyses were performed in Python 3.12, primarily using statsmodels and SciPy. Single-session outcomes and maximum heart rate were analyzed using linear models with participant fixed effects. Small-sample-corrected robust standard errors were calculated with clustering by participant. Overall effects across the three conditions were evaluated using joint F tests. Relative peak vertical force and mean positive vertical impulse were right-skewed and were therefore analyzed on the natural-log scale. Pairwise contrasts were back-transformed and expressed as ratios of geometric means, whereas descriptive statistics were reported on the original scale. Jump outcomes were analyzed as postexercise-minus-preexercise change scores, with separate models for the CMJ and SJ. Within-condition changes were evaluated using paired t tests, and between-condition differences in change were evaluated using within-participant models. Unadjusted p values are reported for overall three-condition effects. The three pairwise comparisons among conditions were adjusted using the Holm method for each outcome. Paired Hedges' g_z, corrected for small-sample bias, was reported as the standardized effect size for paired comparisons. Absolute g_z values were interpreted as trivial (< 0.20), small (0.20 - 0.49), moderate (0.50 - 0.79), or large ($\geq$ 0.80). Primary analyses used all available observations without imputation. Complete-case analyses of jump outcomes and Friedman/Wilcoxon nonparametric analyses were conducted as sensitivity analyses.

Within-session reliability of repeated jump trials

was assessed separately for CMJ and SJ and for PRE and POST measurements, with the three training conditions pooled. Intraclass correlation coefficients with 95% confidence intervals were estimated using a two-way mixed-effects, absolute-agreement, average-measures model [ICC(A,k), k = 3]. Coefficients of variation were calculated as the pooled within-unit standard deviation divided by the grand mean of all included trial observations. Reliability analyses were restricted to testing units with three valid trials and no missing value for the outcome under analysis.

Results

Realized Training Exposure

All 18 participants completed five sets under each condition. Completed repetitions and session volume load are presented in Table 2. VBT involved fewer completed repetitions than PBT and RIR (mean difference for each comparison, -0.94 repetitions; 95% CI, -1.41 to -0.48; Holm-adjusted p = 0.001). Session volume load was higher in RIR than in PBT (mean difference, 36.11 kg; 95% CI, 12.28 to 59.94 kg; Holm-adjusted p = 0.005) and lower in VBT than in PBT (-106.94 kg; 95% CI, -157.30 to -56.59 kg; Holm-adjusted p < 0.001) and RIR (-143.06 kg; 95% CI, -200.88 to -85.23 kg; Holm-adjusted p < 0.001).

Mechanical Output During Training

Session-level relative peak vertical force and mean positive vertical impulse are shown in Figure 1. The geometric means for relative peak vertical force were 1.260, 1.207, and 1.237 times system weight under PBT, RIR, and VBT, respectively (F(2, 17) = 1.123, p = 0.348). The corresponding geometric means for mean positive vertical impulse were 400.2, 353.2, and 388.2 N·s (F(2, 17) = 1.452, p = 0.262).

For VBT versus RIR, the geometric mean ratios were 1.025 for relative peak vertical force (95% CI, 0.988–1.065; Holm-adjusted p = 0.529) and 1.099 for mean positive vertical impulse (95% CI, 0.978–1.235; Holm-adjusted p = 0.320). The remaining pairwise comparisons are reported in Table S5, Supplementary Material.

Mean repetition duration did not show an overall condition effect (PBT, 2.64 $\pm$ 0.26 s; RIR, 2.68 $\pm$ 0.35 s; VBT, 2.53 $\pm$ 0.30 s; p = 0.177). Peak-force and positive-impulse maintenance also showed no overall condition effects (p = 0.976 and p = 0.461, respectively). Exploratory set-by-set analyses identified a linear set effect for positive impulse (p < 0.001), without a clear condition-by-set interaction (p = 0.090). Supporting session-level outcomes, maximum heart rate, and set-by-set trajectories are reported in Table S1 and Figures S1–S2, Supplementary Material.

Table 2. Realized training exposure across the three back-squat protocols

Variable	PBT	RIR	VBT
Completed sets (n)	5	5	5
Mean external load per set (kg)	120.00 $\pm$ 17.38	121.44 $\pm$ 16.31	120.00 $\pm$ 17.38
Completed repetitions per session (n)	25.00 $\pm$ 0.00	25.00 $\pm$ 0.00	24.06 $\pm$ 0.94
Session volume load (kg)	3000.00 $\pm$ 434.60	3036.11 $\pm$ 407.64	2893.06 $\pm$ 474.82

Values are mean $\pm$ SD across 18 participants, except for the fixed number of sets. Session volume load was calculated as the sum of external load $\times$ completed repetitions across five sets. PBT, percentage-based training; RIR, repetitions in reserve; VBT, velocity-based training.

Countermovement-jump responses

Mean changes in CMJ jump height were -0.29 cm (95% CI, -1.28 to 0.69), -0.09 cm (95% CI, -2.13 to 1.96), and -0.27 cm (95% CI, -1.34 to 0.81) after PBT, RIR, and VBT, respectively, with no overall condition effect ($F(2, 17) = 0.032$, $p = 0.969$; Figure 2A). The corresponding changes in modified reactive strength index (RSImod) were $+0.005$, -0.003 , and -0.016 $\text{m} \cdot \text{s}^{-1}$, respectively ($F(2, 17) = 0.113$, $p = 0.894$; Figure 2B). Additional CMJ force–time outcomes are provided in Table S2 and Figure S3; detailed pairwise comparisons are reported in Table S5, Supplementary Material.

Squat-jump responses

Mean changes in SJ jump height were $+0.14$ cm (95% CI, -1.95 to 2.24), -1.38 cm (95% CI, -4.40 to 1.64), and $+1.63$ cm (95% CI, -4.21 to 7.48) after PBT, RIR, and VBT, respectively. No overall condition effect was observed ($F(2, 17) = 0.306$, $p = 0.740$; Figure 3). Other SJ force–time outcomes are provided in Table S3 and Figure S4; pairwise comparisons are reported in Table S5, Supplementary Material. Within-session reliability statistics for the CMJ and SJ outcomes are presented in Table S6, Supplementary Material.

Sensitivity analyses

Complete-case CMJ and SJ analyses did not identify overall condition effects (Table S4A, Supplementary Material).

In nonparametric analyses, relative peak vertical force showed an overall condition effect (Friedman $p = 0.029$), but the VBT-versus-PBT contrast did not meet the Holm-adjusted significance threshold ($p = 0.062$). Mean repetition duration showed a VBT-versus-RIR difference in the nonparametric analysis (Holm-adjusted $p = 0.042$), whereas the primary model showed no overall condition effect ($p = 0.177$). Complete sensitivity results are reported in Table S4B, Supplementary Material.

Discussion

Principal findings

The primary analyses did not detect statistically significant overall condition effects on session-level relative peak vertical force, mean positive vertical impulse, or immediate CMJ and SJ outcomes. These results do not demonstrate that the three protocols produced the same responses. All protocols began at 80% 1RM, included five sets, and capped each set at five repetitions, but their implemented training exposures differed. VBT involved fewer completed repetitions and a lower session volume load than PBT and RIR, while RIR permitted between-set load adjustments. With 18 participants, the study had limited sensitivity to smaller effects. The estimates therefore pertain to the implemented protocols and cannot isolate the effect of the monitoring method or establish that the protocols are interchangeable.

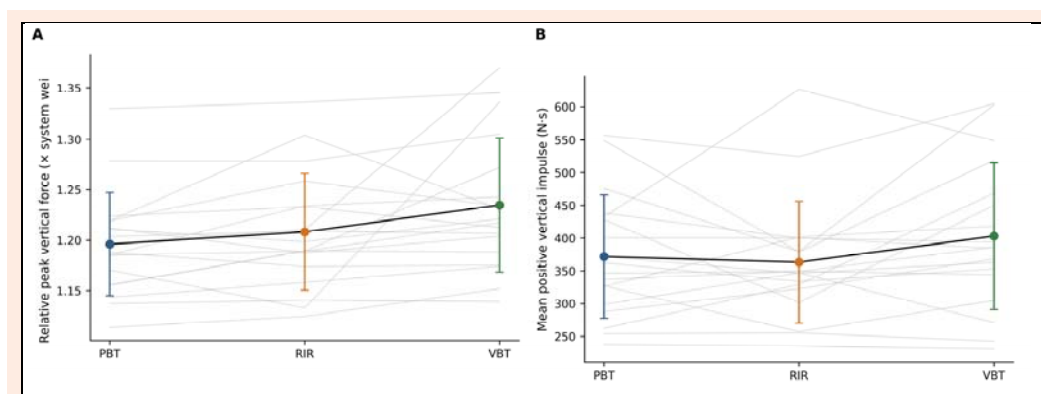


Figure 1. Session-level mechanical output during back-squat training under PBT, RIR, and VBT. (A) Relative peak vertical force; (B) mean positive vertical impulse. Light-gray lines represent individual participant data, black lines connect condition means, and colored circles with error bars represent arithmetic means $\pm$ standard deviations. Blue, orange, and green indicate PBT, RIR, and VBT, respectively. Relative peak vertical force was normalized using the calibration force recorded separately for each set. The corresponding log-scale inferential results are reported in the text and Tables S1 and S5.

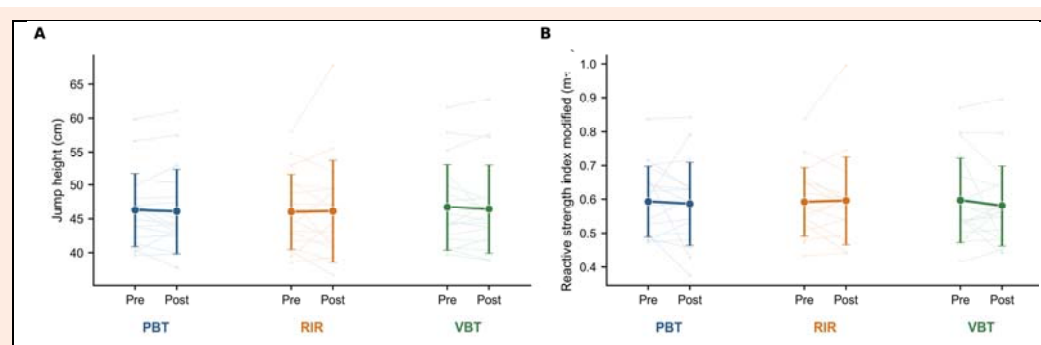


Figure 2. Pre- to postexercise CMJ responses under the three load-regulation protocols. (A) Jump height; (B) modified reactive strength index (RSImod). Light-colored lines represent individual pre- to postexercise changes, colored solid lines connect condition means, and colored circles with error bars represent mean $\pm$ standard deviation. Blue, orange, and green indicate PBT, RIR, and VBT, respectively. Jump height was calculated using the impulse–momentum method.

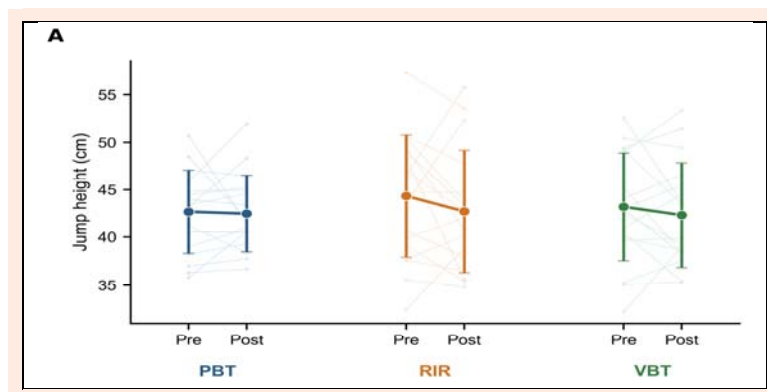


Figure 3. Pre- to postexercise squat-jump height under the three load-regulation protocols. Light-colored lines represent individual pre- to postexercise changes, colored solid lines connect condition means, and colored circles with error bars represent mean $\pm$ standard deviation. Blue, orange, and green indicate PBT, RIR, and VBT, respectively. Jump height was calculated using the impulse-momentum method.

This interpretation is consistent with the broader evidence. A meta-analysis of six studies involving 124 participants found no significant differences between VBT and PBT in squat 1RM, jump performance, linear sprint performance, or change-of-direction performance; the pooled mean difference in squat 1RM was 3.03 kg (95% CI, -3.55 to 9.61) (Liao et al., 2021). A second meta-analysis of four randomized trials and 88 participants reported standardized mean differences of 0.06, 0.11, and -0.10 for strength, power, and sprint speed, respectively (Orange et al., 2022). Collectively, these syntheses do not demonstrate a consistent advantage of VBT over PBT. The value of a monitoring tool ultimately depends on whether its feedback changes the load, repetitions per set, or proximity to task failure.

Mechanical output during back-squat training

The primary mechanical analyses did not detect an overall condition effect, a result that may reflect, in part, the specified within-set regulation rules. Velocity loss and RIR can provide information about proximity to task failure (Rodríguez-Rosell et al., 2020). At 75% 1RM, a comparison of failure, 1-RIR, and 3-RIR bench-press conditions showed that earlier set termination reduced both velocity loss and postexercise neuromuscular fatigue (Refalo et al., 2023). In the present study, the RIR protocol targeted 3-RIR, the VBT protocol used a 20% velocity-loss threshold with a five-repetition cap, and the PBT protocol used five repetitions per set. These rules limited the permitted repetition range but did not produce identical training exposures. Graham and Cleather (2021) paired five repetitions at 80% 1RM with a target of 3 RIR as a theoretical prescription match. In our study, RIR allowed between-set load adjustments and resulted in a higher recorded session volume load than PBT; the theoretical prescription match therefore should not be taken as an equivalent realized stimulus.

A closely matched acute protocol using 80% 1RM, five sets, and no more than five repetitions per set produced higher mean and peak velocities under a 20% velocity-loss condition than under PBT, with effect sizes of approximately 0.81 and 0.98, whereas most force and power outcomes did not differ (Banyard et al., 2019). Barbell kinematics and ground-reaction kinetics do not necessarily

change in parallel. Barbell velocity reflects the rate of displacement of the external load, whereas force-plate peak force and impulse reflect the vertical interaction of the athlete-barbell system with the ground. Adjustments in movement amplitude, center-of-mass motion, and force-application timing may therefore allow higher barbell velocity to coexist with similar ground-reaction forces.

Real-time feedback can alter the training stimulus only when it changes training behavior. A systematic review of 20 studies indicated that immediate feedback generally improves acute velocity or power performance, although the magnitude of the effect depends on feedback format, frequency, and task (Weakley et al., 2023). In the present study, RIR permitted between-set load adjustments, whereas VBT maintained a constant load and used velocity loss to terminate sets. The five-repetition cap limited the extent to which the VBT termination rule could modify training exposure, particularly when the velocity-loss threshold was not reached before the fifth repetition. The exploratory set-by-set analysis showed a change in positive impulse across sets without a clear condition-specific trajectory (Figure S2, Supplementary Material).

Postexercise jump responses

Mean changes in CMJ and SJ jump height were generally small in this sample, although the SJ estimates were imprecise. In resistance-trained men, three sets of squats to failure at approximately 60% 1RM reduced CMJ height by 25%-32% immediately after exercise, with values remaining 6.7%-7.9% below baseline at 24 and 48 h; mean propulsive velocity under a standardized load decreased by 13%-14% (Párraga-Montilla et al., 2020). Another study reported that failure training prolonged neuromuscular, metabolic, and hormonal recovery for 24 - 48 h, whereas earlier set termination accelerated recovery (Morán-Navarro et al., 2017). Relative to these higher-fatigue protocols, the average immediate CMJ changes observed here were small; nevertheless, the estimates do not establish identical postexercise responses among PBT, RIR, and VBT.

The velocity-loss literature provides further context. Systematic review and meta-analytic evidence indicates that greater velocity loss is generally accompanied by greater acute neuromuscular and metabolic stress (Jukic et

al., 2023). Over longer training periods, lower velocity-loss thresholds appear more favorable for jump, sprint, and sub-maximal-load velocity performance, whereas higher thresholds tend to favor hypertrophic adaptation (Jukic et al., 2023). In acute recovery studies, training at 80% 1RM with a 20% velocity-loss threshold has also been associated with relatively rapid recovery of CMJ performance (Pareja-Blanco et al., 2019).

The present study examined jump height, RSImod, power, and propulsive impulse. Previous force-time studies suggest that power- and impulse-related CMJ metrics may provide additional information when changes in jump height are small (Gathercole et al., 2015; Hughes et al., 2022). Meta-analytic evidence also indicates that the mean of multiple trials is more suitable for monitoring neuromuscular status than the single best trial (Claudino et al., 2017).

Practical implications and longer-term context

The absence of detected differences in immediate outcomes does not determine whether longer-term adaptations differ. Meta-analytic evidence suggests that any long-term advantage of autoregulation over fixed-percentage loading is generally small and context dependent, while lower velocity-loss thresholds may be favorable for selected strength, jump, and sprint outcomes (Hickmott et al., 2022; Held et al., 2022; Larsen et al., 2021). Individual interventions have likewise reported selective benefits of VBT despite lower training volume (Dorrell et al., 2020; Pareja-Blanco et al., 2017), and a study in sprinters reported greater squat-strength and 20-m sprint improvements with VBT than PBT while CMJ gains were similar (Guo et al., 2026). RIR and VBT rely on different information: RIR depends on perceptual accuracy and familiarization, whereas VBT provides objective repetition-by-repetition information (Helms et al., 2017; Halperin et al., 2022; Refalo et al., 2024; Jukic et al., 2024). The present acute comparison cannot determine whether one prescription method should replace another in practice or whether their longer-term effects are equivalent.

Limitations

This study has several limitations. First, the realized training stimulus was not fully matched across conditions. The PBT condition used a fixed load of 80% 1RM across all five sets and did not permit within-session load progression. Although this standardized approach facilitated comparison among the three protocols, it may not fully reflect common strength-and-conditioning practice, in which loads may be prescribed within a range and adjusted across sets according to performance. Accordingly, the present findings for PBT should be interpreted as applying to the fixed-load protocol examined here rather than to all forms of percentage-based training. Although the external load, completed repetitions, and session volume load were documented, differences in these variables may have contributed to the observed mechanical and postexercise responses. The study was therefore not designed to isolate the independent effects of the three load-regulation methods. The session-level mechanical outcomes were averaged across all valid force-time cycles and therefore did not represent comparisons of matched repetition positions at

identical external loads. Because the training force-time analysis was based on complete segmented cycles rather than separate identification of the braking and propulsion phases, the present data do not permit phase-specific interpretation of net force or force-production strategy. Differences in completed repetitions and RIR-related load adjustments may have influenced these averages, despite the use of set-specific system-weight normalization for relative peak vertical force. Second, the sample consisted of 18 male sprinters. Pairwise multiplicity adjustment was outcome-specific, and secondary and exploratory findings were interpreted cautiously. The sensitivity power analysis indicated that the completed design had 80% power to detect an omnibus effect of approximately $f = 0.31$, so smaller between-condition effects may have remained undetected. Third, outcomes were assessed only immediately after training, and the study did not assess recovery over 24–48 h, blood lactate, or muscle soreness. Finally, the study was not designed as an equivalence trial; consequently, nonsignificant condition effects should not be interpreted as evidence that the strategies are equivalent.

Conclusion

In 18 trained male sprinters completing five-set back-squat sessions beginning at 80% 1RM, the primary analyses did not detect statistically significant overall condition effects on session-level relative peak vertical force, mean positive vertical impulse, CMJ jump height, or CMJ RSImod; the corresponding SJ jump-height comparison was also nonsignificant. Realized repetition volume and session volume load differed among PBT, RIR, and VBT. These findings characterize the implemented protocols rather than the independent effects of their monitoring methods. The study was not designed to establish equivalence, and the nonsignificant results do not demonstrate that the protocols elicit the same response or can be used interchangeably.

Acknowledgements

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Key points

- No statistically significant overall condition effects were detected for session-level relative peak vertical force or mean positive vertical impulse in these 18 sprinters.
- The CMJ and SJ analyses did not detect overall condition effects; smaller differences in immediate jump responses remain possible.
- Despite a shared starting intensity and five-set structure, the protocols produced different realized repetition and volume loads.
- These results compare complete training protocols and do not establish equivalence or interchangeability among PBT, RIR, and VBT.

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Supplementary Material

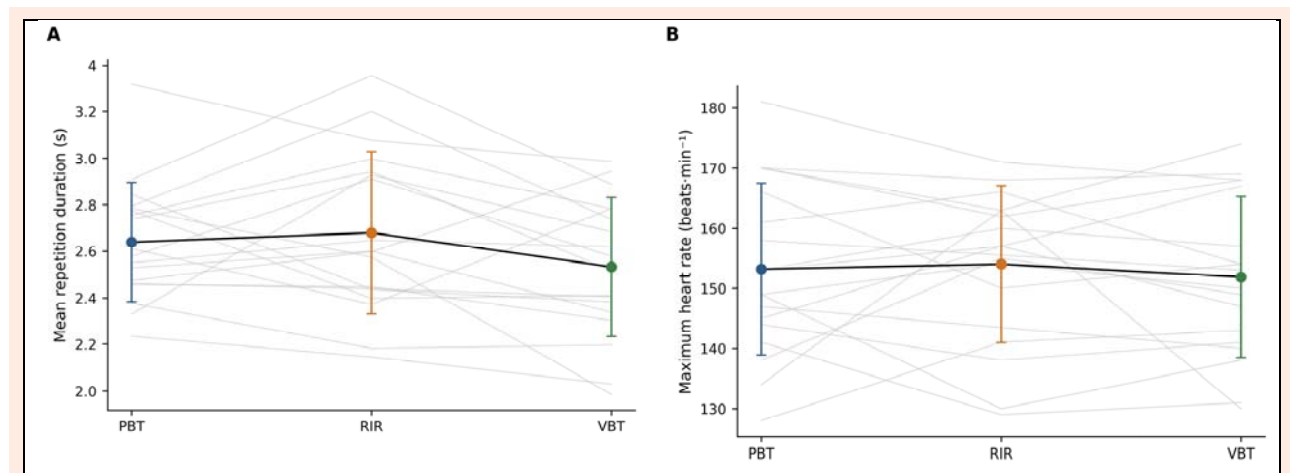


Figure S1. Supporting training-session outcomes under the three load-regulation protocols. (A) Mean repetition duration; (B) maximum heart rate. Individual values are shown in light gray; colored circles and error bars represent mean $\pm$ standard deviation. PBT, RIR, and VBT are shown in blue, orange, and green, respectively.

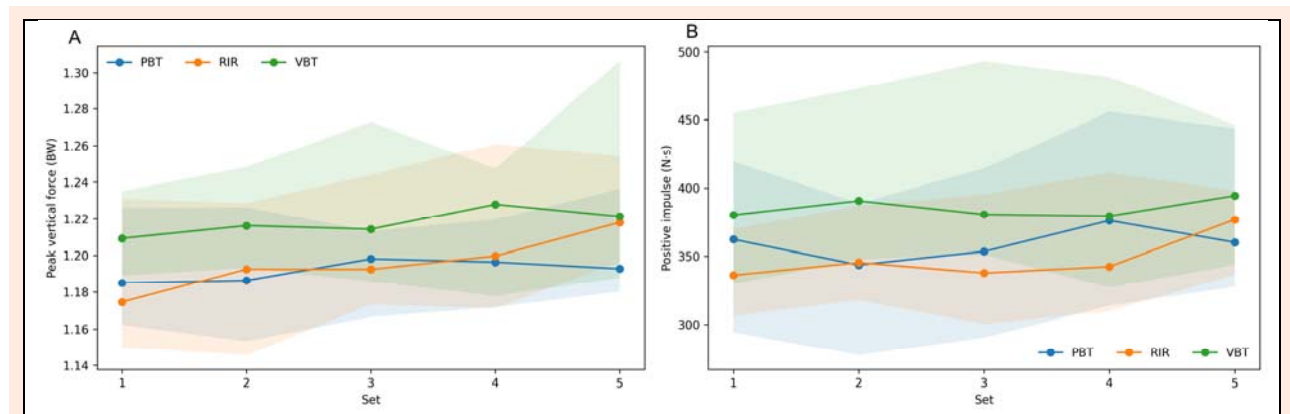


Figure S2. Exploratory set-by-set trajectories across five back-squat sets. (A) Relative peak vertical force; (B) mean positive vertical impulse. Solid lines represent condition medians and shaded regions show interquartile ranges. Relative peak vertical force was normalized to the set-specific athlete-barbell calibration force. PBT, RIR, and VBT are shown in blue, orange, and green, respectively. Exploratory set-by-set model results: relative peak vertical force (condition $p = 0.208$, linear set $p = 0.055$, interaction $p = 0.994$); mean positive vertical impulse (condition $p = 0.142$, linear set $p < 0.001$, interaction $p = 0.090$); and mean repetition duration (condition $p = 0.106$, linear set $p = 0.055$, interaction $p = 0.213$).

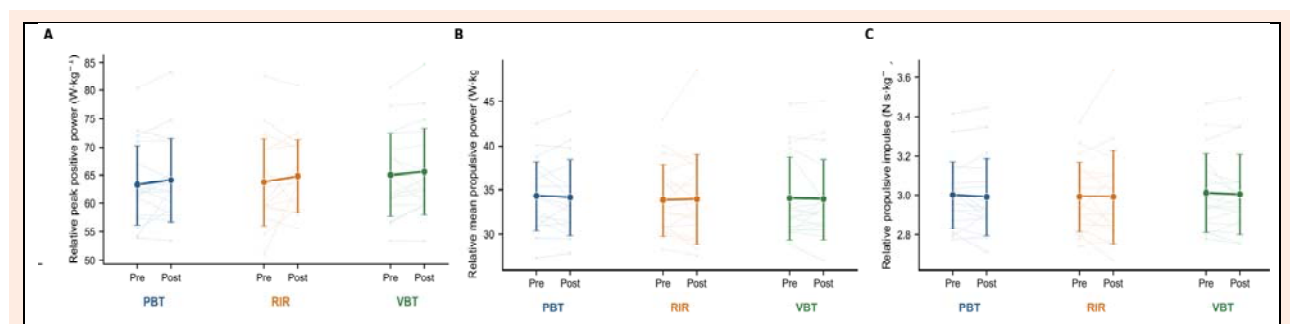


Figure S3. Supporting CMJ force-time outcomes under the three load-regulation protocols. (A) Relative peak positive power; (B) relative mean propulsive power; (C) relative propulsive impulse. Light-colored lines represent individual pre- to postexercise changes, colored solid lines connect condition means, and colored circles with error bars represent mean $\pm$ standard deviation. Power and impulse were normalized to body mass.

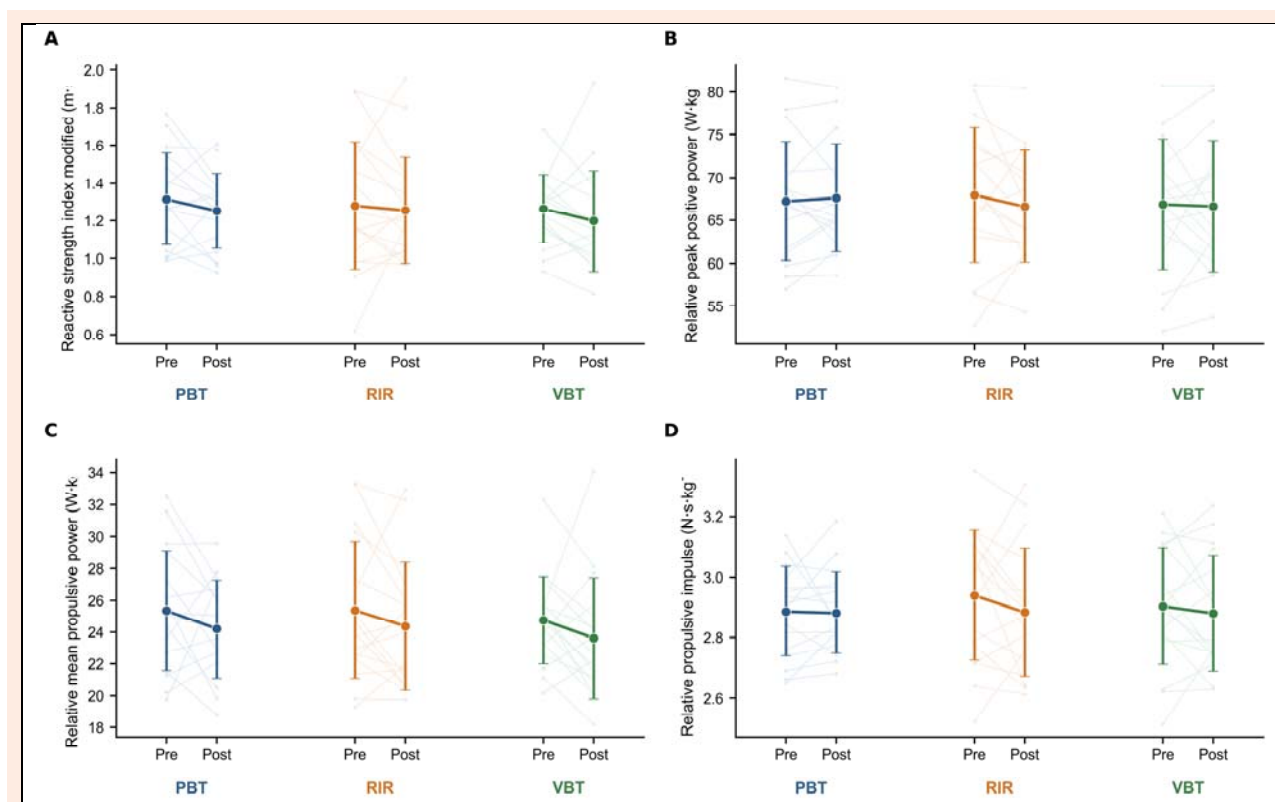


Figure S4. Supporting squat-jump force-time outcomes under the three load-regulation protocols. (A) Modified reactive strength index (RSImod); (B) relative peak positive power; (C) relative mean propulsive power; (D) relative propulsive impulse. Light-colored lines represent individual pre- to postexercise changes, colored solid lines connect condition means, and colored circles with error bars represent mean $\pm$ standard deviation. Power and impulse were normalized to body mass.

Table S1. Session-level mechanical output and maximum heart rate (Main Figure 1 and Supplementary Figure S1).

Outcome	PBT	RIR	VBT	F (df1, df2)	p value
Relative peak vertical force ($\times$ system weight)	1.260 (n = 18)	1.207 (n = 18)	1.237 (n = 18)	1.123 (2, 17)	0.348
Mean positive vertical impulse (N·s)	400.2 (n = 18)	353.2 (n = 18)	388.2 (n = 18)	1.452 (2, 17)	0.262
Mean repetition duration (s)	2.64 $\pm$ 0.26 (n = 18)	2.68 $\pm$ 0.35 (n = 18)	2.53 $\pm$ 0.30 (n = 18)	1.917 (2, 17)	0.177
Peak vertical force maintenance (%)	101.89 $\pm$ 4.70 (n = 18)	102.30 $\pm$ 4.60 (n = 17)	102.21 $\pm$ 6.76 (n = 18)	0.024 (2, 17)	0.976
Positive impulse maintenance (%)	109.99 $\pm$ 13.84 (n = 18)	112.95 $\pm$ 21.95 (n = 17)	101.81 $\pm$ 17.88 (n = 18)	0.810 (2, 17)	0.461
Maximum heart rate (beats·min ⁻¹)	153.17 $\pm$ 14.30 (n = 18)	154.00 $\pm$ 13.04 (n = 16)	151.83 $\pm$ 13.39 (n = 18)	0.258 (2, 17)	0.776

Relative peak vertical force and mean positive vertical impulse are reported as geometric means because inference was conducted on the natural-log scale; all other descriptive values are mean $\pm$ SD. The p values are unadjusted overall condition-effect tests. Pairwise comparisons are reported in Table S5 and were adjusted using the Holm method. Peak-force and impulse maintenance were calculated as set 5 / set 1 $\times$ 100%. Abbreviations: PBT, percentage-based training; RIR, repetitions in reserve; VBT, velocity-based training.

Table S2. CMJ outcomes before and after training (Main Figure 2 and Supplementary Figure S3).

Condition		PRE	POST	Δ [95% CI]	F (2, 17)	p value
Jump height (cm)	PBT	46.29 $\pm$ 5.43 (n = 18)	46.10 $\pm$ 6.26 (n = 17)	-0.29 [-1.28, 0.69] (n = 17)	0.032	0.969
	RIR	46.03 $\pm$ 5.57 (n = 18)	46.13 $\pm$ 7.59 (n = 17)	-0.09 [-2.13, 1.96] (n = 17)		
	VB T	46.72 $\pm$ 6.36 (n = 18)	46.46 $\pm$ 6.55 (n = 18)	-0.27 [-1.34, 0.81] (n = 18)		
Modified reactive strength index (m·s ⁻¹)	PBT	0.576 $\pm$ 0.124 (n = 18)	0.587 $\pm$ 0.123 (n = 17)	+0.005 [-0.068, 0.079] (n = 17)	0.113	0.894
	RIR	0.592 $\pm$ 0.102 (n = 18)	0.596 $\pm$ 0.130 (n = 17)	-0.003 [-0.036, 0.029] (n = 17)		
	VB T	0.597 $\pm$ 0.125 (n = 18)	0.580 $\pm$ 0.118 (n = 18)	-0.016 [-0.056, 0.023] (n = 18)		
Relative peak positive power (W·kg ⁻¹)	PBT	61.03 $\pm$ 12.12 (n = 18)	62.33 $\pm$ 12.15 (n = 17)	+1.37 [-1.11, 3.84] (n = 17)	1.133	0.345
	RIR	62.07 $\pm$ 12.42 (n = 18)	65.42 $\pm$ 8.23 (n = 17)	+3.22 [-2.32, 8.76] (n = 17)		
	VB T	65.05 $\pm$ 7.39 (n = 18)	62.86 $\pm$ 12.67 (n = 18)	-2.18 [-6.83, 2.46] (n = 18)		
Relative mean propulsive power (W·kg ⁻¹)	PBT	34.32 $\pm$ 3.95 (n = 18)	34.16 $\pm$ 4.32 (n = 17)	-0.34 [-1.17, 0.49] (n = 17)	0.058	0.944
	RIR	33.85 $\pm$ 4.10 (n = 18)	33.95 $\pm$ 5.10 (n = 17)	-0.15 [-1.36, 1.06] (n = 17)		
	VB T	34.06 $\pm$ 4.68 (n = 18)	33.96 $\pm$ 4.54 (n = 18)	-0.10 [-0.99, 0.78] (n = 18)		
Relative propulsive impulse (N·s·kg ⁻¹)	PBT	3.001 $\pm$ 0.173 (n = 18)	2.991 $\pm$ 0.198 (n = 17)	-0.013 [-0.046, 0.020] (n = 17)	0.014	0.986
	RIR	2.993 $\pm$ 0.179 (n = 18)	2.992 $\pm$ 0.237 (n = 17)	-0.007 [-0.071, 0.057] (n = 17)		
	VB T	3.012 $\pm$ 0.200 (n = 18)	3.004 $\pm$ 0.205 (n = 18)	-0.008 [-0.041, 0.026] (n = 18)		

PRE and POST values are mean $\pm$ SD. Changes are POST – PRE means with 95% confidence intervals; the paired sample size is shown in each change cell. F and p values test whether PRE-to-POST changes differed among PBT, RIR, and VB T. Pairwise comparisons are reported in Table S5. Jump height was calculated using the impulse–momentum method; power and propulsive impulse were normalized to body mass. Abbreviations: PBT, percentage-based training; RIR, repetitions in reserve; VB T, velocity-based training; CMJ, countermovement jump.

Table S3. SJ outcomes before and after training (Main Figure 3 and Supplementary Figure S4).

Condition		PRE	POST	Δ [95% CI]	F(2, 17)	p value
Jump height (cm)	PBT	42.68 $\pm$ 4.38 (n = 17)	42.48 $\pm$ 4.04 (n = 17)	+0.14 [-1.95, 2.24] (n = 16)	0.306	0.740
	RIR	44.34 $\pm$ 6.44 (n = 18)	42.72 $\pm$ 6.44 (n = 17)	-1.38 [-4.40, 1.64] (n = 17)		
	VB T	43.20 $\pm$ 5.67 (n = 18)	44.68 $\pm$ 11.83 (n = 17)	+1.63 [-4.21, 7.48] (n = 17)		
Modified reactive strength index (m·s ⁻¹)	PBT	1.315 $\pm$ 0.243 (n = 17)	1.253 $\pm$ 0.200 (n = 17)	-0.065 [-0.168, 0.038] (n = 16)	0.322	0.729
	RIR	1.281 $\pm$ 0.337 (n = 18)	1.256 $\pm$ 0.280 (n = 17)	-0.024 [-0.155, 0.106] (n = 17)		
	VB T	1.264 $\pm$ 0.182 (n = 18)	1.199 $\pm$ 0.267 (n = 17)	-0.054 [-0.164, 0.055] (n = 17)		
Relative peak positive power (W·kg ⁻¹)	PBT	67.23 $\pm$ 6.92 (n = 17)	67.62 $\pm$ 6.30 (n = 17)	-0.09 [-2.04, 1.86] (n = 16)	0.136	0.873
	RIR	67.96 $\pm$ 7.85 (n = 18)	67.21 $\pm$ 8.08 (n = 17)	-0.87 [-4.00, 2.25] (n = 17)		
	VB T	66.87 $\pm$ 7.57 (n = 18)	67.82 $\pm$ 9.71 (n = 17)	+1.42 [-3.13, 5.97] (n = 17)		
Relative mean propulsive power (W·kg ⁻¹)	PBT	25.36 $\pm$ 3.76 (n = 17)	24.20 $\pm$ 3.09 (n = 17)	-0.97 [-2.92, 0.99] (n = 16)	0.194	0.825
	RIR	24.84 $\pm$ 5.18 (n = 18)	24.37 $\pm$ 4.01 (n = 17)	-0.32 [-2.52, 1.88] (n = 17)		
	VB T	24.75 $\pm$ 2.76 (n = 18)	23.62 $\pm$ 3.81 (n = 17)	-1.05 [-2.91, 0.81] (n = 17)		
Relative propulsive impulse (N·s·kg ⁻¹)	PBT	2.887 $\pm$ 0.148 (n = 17)	2.882 $\pm$ 0.134 (n = 17)	+0.007 [-0.061, 0.075] (n = 16)	0.353	0.708
	RIR	2.939 $\pm$ 0.215 (n = 18)	2.884 $\pm$ 0.211 (n = 17)	-0.047 [-0.145, 0.051] (n = 17)		
	VB T	2.904 $\pm$ 0.193 (n = 18)	2.940 $\pm$ 0.349 (n = 17)	+0.041 [-0.129, 0.211] (n = 17)		

PRE and POST values are mean $\pm$ SD. Changes are POST – PRE means with 95% confidence intervals; the paired sample size is shown in each change cell. F and p values test whether PRE-to-POST changes differed among PBT, RIR, and VB T. Pairwise comparisons are reported in Table S5. Jump height was calculated using the impulse–momentum method; power and propulsive impulse were normalized to body mass. Abbreviations: PBT, percentage-based training; RIR, repetitions in reserve; VB T, velocity-based training; SJ, squat jump.

Table S4A. Complete-case analysis of jump outcomes (Only participants with complete PRE and POST data under all three conditions were included).

Jump type	Outcome	Unit	n	F(df1, df2)	p value
CMJ	Jump height	cm	17	0.032 (2, 16)	0.968
CMJ	Modified reactive strength index	m·s ⁻¹	17	0.115 (2, 16)	0.892
CMJ	Relative peak positive power	W·kg ⁻¹	17	1.152 (2, 16)	0.341
CMJ	Relative mean propulsive power	W·kg ⁻¹	17	0.059 (2, 16)	0.943
CMJ	Relative propulsive impulse	N·s·kg ⁻¹	17	0.014 (2, 16)	0.986
SJ	Jump height	cm	15	0.317 (2, 14)	0.733
SJ	Modified reactive strength index	m·s ⁻¹	15	0.385 (2, 14)	0.688
SJ	Relative peak positive power	W·kg ⁻¹	15	0.045 (2, 14)	0.956
SJ	Relative mean propulsive power	W·kg ⁻¹	15	0.229 (2, 14)	0.799
SJ	Relative propulsive impulse	N·s·kg ⁻¹	15	0.338 (2, 14)	0.719

Values are unadjusted overall condition-effect tests based on PRE-to-POST changes. CMJ, countermovement jump; SJ, squat jump.

Table S4B. Nonparametric sensitivity analyses (Friedman tests assessed overall condition differences; Wilcoxon signed-rank pairwise comparisons were adjusted using the Holm method).

Domain	Outcome	Unit	n	Friedman χ^2	df	Overall p	RIR vs PBT pHolm	VBT vs PBT pHolm	VBT vs RIR pHolm
Training session	Relative peak vertical force	× system weight	18	7.111	2	0.029	0.304	0.062	0.120
Training session	Mean positive vertical impulse	N·s	18	0.333	2	0.846	0.834	0.834	0.145
Training session	Mean repetition duration	s	18	6.778	2	0.034	0.640	0.217	0.042
Training session	Peak vertical force maintenance	%	17	0.824	2	0.662	1.000	1.000	1.000
Training session	Positive impulse maintenance	%	17	0.471	2	0.790	0.918	0.918	0.918
CMJ	Jump height	cm	17	0.353	2	0.838	1.000	1.000	1.000
CMJ	Modified reactive strength index	m·s ⁻¹	17	0.471	2	0.790	1.000	1.000	1.000
CMJ	Relative peak positive power	W·kg ⁻¹	17	2.471	2	0.291	0.570	0.644	0.570
CMJ	Relative mean propulsive power	W·kg ⁻¹	17	0.471	2	0.790	1.000	1.000	1.000
CMJ	Relative propulsive impulse	N·s·kg ⁻¹	17	0.118	2	0.943	1.000	1.000	1.000
SJ	Jump height	cm	15	0.933	2	0.627	1.000	1.000	1.000
SJ	Modified reactive strength index	m·s ⁻¹	15	0.933	2	0.627	0.991	1.000	1.000
SJ	Relative peak positive power	W·kg ⁻¹	15	0.133	2	0.936	1.000	1.000	1.000
SJ	Relative mean propulsive power	W·kg ⁻¹	15	0.133	2	0.936	1.000	1.000	1.000
SJ	Relative propulsive impulse	N·s·kg ⁻¹	15	0.933	2	0.627	1.000	1.000	1.000

Holm-adjusted p values are reported for pairwise comparisons; values <0.05 are highlighted.

Training-session, CMJ, and SJ outcomes are detailed in Tables S1-S3; primary figure panels are shown in Figures 1-3.

Table S5. Pairwise comparisons among training conditions (*Pairwise comparisons were adjusted within each outcome using the Holm method*).

Domain	Outcome	Unit	Contrast	n	Effect measure	Estimate [95% CI]	Hedges' g _z	p value	Holm- adjusted p
Single session	Mean repetition duration	s	RIR vs PBT	18	Mean difference	0.041 [-0.141, 0.222]	0.133	0.643	0.643
Single session	Mean repetition duration	s	VB T vs PBT	18	Mean difference	-0.108 [-0.289, 0.074]	-0.352	0.228	0.457
Single session	Mean repetition duration	s	VB T vs RIR	18	Mean difference	-0.148 [-0.312, 0.015]	-0.537	0.073	0.219
Single session	Relative peak vertical force	× system weight	RIR vs PBT	18	Geometric mean ratio	0.958 [0.833, 1.102]	-0.182	0.526	1.000
Single session	Relative peak vertical force	× system weight	VB T vs PBT	18	Geometric mean ratio	0.982 [0.875, 1.103]	-0.092	0.749	1.000
Single session	Relative peak vertical force	× system weight	VB T vs RIR	18	Geometric mean ratio	1.025 [0.988, 1.065]	0.396	0.176	0.529
Single session	Mean positive vertical impulse	N·s	RIR vs PBT	18	Geometric mean ratio	0.883 [0.625, 1.246]	-0.215	0.455	0.911
Single session	Mean positive vertical impulse	N·s	VB T vs PBT	18	Geometric mean ratio	0.970 [0.709, 1.326]	-0.057	0.840	0.911
Single session	Mean positive vertical impulse	N·s	VB T vs RIR	18	Geometric mean ratio	1.099 [0.978, 1.235]	0.479	0.107	0.320
Single session	Peak vertical force maintenance	%	RIR vs PBT	17	Mean difference	0.255 [-3.657, 4.166]	0.041	0.892	1.000
Single session	Peak vertical force maintenance	%	VB T vs PBT	18	Mean difference	0.323 [-4.007, 4.653]	0.045	0.877	1.000
Single session	Peak vertical force maintenance	%	VB T vs RIR	17	Mean difference	0.068 [-6.058, 6.195]	0.008	0.981	1.000
Single session	Positive impulse maintenance	%	RIR vs PBT	17	Mean difference	2.248 [-12.460, 16.956]	0.107	0.751	0.751
Single session	Positive impulse maintenance	%	VB T vs PBT	18	Mean difference	-8.172 [-24.399, 8.056]	-0.300	0.303	0.720
Single session	Positive impulse maintenance	%	VB T vs RIR	17	Mean difference	-10.420 [-28.481, 7.641]	-0.335	0.240	0.720
Single session	Maximum heart rate	beats·min ⁻¹	RIR vs PBT	16	Mean difference	0.458 [-8.045, 8.962]	0.054	0.911	1.000
Single session	Maximum heart rate	beats·min ⁻¹	VB T vs PBT	18	Mean difference	-1.333 [-6.682, 4.015]	-0.149	0.606	1.000
Single session	Maximum heart rate	beats·min ⁻¹	VB T vs RIR	16	Mean difference	-1.792 [-8.889, 5.306]	-0.133	0.601	1.000
CMJ	Jump height	cm	RIR vs PBT	17	Difference in PRE-to-POST change	0.207 [-2.173, 2.587]	0.053	0.857	1.000
CMJ	Jump height	cm	VB T vs PBT	17	Difference in PRE-to-POST change	-0.070 [-1.488, 1.347]	-0.030	0.918	1.000

Table S5. Continue...

Domain	Outcome	Unit	Contrast	n	Effect measure	Estimate [95% CI]	Hedges' g _z	p value	Holm- adjusted p
CMJ	Jump height	cm	VBТ vs RIR	17	Difference in PRE-to-POST change	-0.277 [-2.618, 2.064]	-0.072	0.806	1.000
CMJ	Modified reactive strength index	m·s ⁻¹	RIR vs PBT	17	Difference in PRE-to-POST change	-0.008 [-0.089, 0.073]	-0.063	0.831	1.000
CMJ	Modified reactive strength index	m·s ⁻¹	VBТ vs PBT	17	Difference in PRE-to-POST change	-0.023 [-0.145, 0.099]	-0.116	0.695	1.000
CMJ	Modified reactive strength index	m·s ⁻¹	VBТ vs RIR	17	Difference in PRE-to-POST change	-0.015 [-0.080, 0.051]	-0.138	0.642	1.000
CMJ	Relative peak positive power	W·kg ⁻¹	RIR vs PBT	17	Difference in PRE-to-POST change	1.857 [-5.865, 9.579]	0.148	0.618	0.618
CMJ	Relative peak positive power	W·kg ⁻¹	VBТ vs PBT	17	Difference in PRE-to-POST change	-3.769 [-10.341, 2.802]	-0.352	0.243	0.552
CMJ	Relative peak positive power	W·kg ⁻¹	VBТ vs RIR	17	Difference in PRE-to-POST change	-5.627 [-14.199, 2.945]	-0.403	0.184	0.552
CMJ	Relative mean propulsive power	W·kg ⁻¹	RIR vs PBT	17	Difference in PRE-to-POST change	0.189 [-1.296, 1.675]	0.078	0.791	1.000
CMJ	Relative mean propulsive power	W·kg ⁻¹	VBТ vs PBT	17	Difference in PRE-to-POST change	0.201 [-1.238, 1.640]	0.086	0.771	1.000
CMJ	Relative mean propulsive power	W·kg ⁻¹	VBТ vs RIR	17	Difference in PRE-to-POST change	0.012 [-1.628, 1.652]	0.005	0.988	1.000
CMJ	Relative propulsive impulse	N·s·kg ⁻¹	RIR vs PBT	17	Difference in PRE-to-POST change	0.006 [-0.069, 0.080]	0.048	0.872	1.000
CMJ	Relative propulsive im- pulse	N·s·kg ⁻¹	VBТ vs PBT	17	Difference in PRE-to-POST change	0.002 [-0.045, 0.049]	0.024	0.936	1.000
CMJ	Relative propulsive impulse	N·s·kg ⁻¹	VBТ vs RIR	17	Difference in PRE-to-POST change	-0.004 [-0.078, 0.070]	-0.033	0.911	1.000
SJ	Jump height	cm	RIR vs PBT	16	Difference in PRE-to-POST change	-1.097 [-4.499, 2.305]	-0.154	0.505	1.000
SJ	Jump height	cm	VBТ vs PBT	15	Difference in PRE-to-POST change	1.389 [-7.011, 9.788]	0.066	0.732	1.000
SJ	Jump height	cm	VBТ vs RIR	16	Difference in PRE-to-POST change	2.486 [-6.408, 11.379]	0.193	0.563	1.000
SJ	Modified reactive strength index	m·s ⁻¹	RIR vs PBT	16	Difference in PRE-to-POST change	0.055 [-0.091, 0.202]	0.285	0.437	1.000

Domain	Outcome	Unit	Contrast	n	Effect measure	Estimate [95% CI]	Hedges' g _z	p value	Holm- adjusted p
SJ	Modified reactive strength index	m·s ⁻¹	VBT vs PBT	15	Difference in PRE-to-POST change	0.016 [-0.163, 0.195]	0.012	0.854	1.000
SJ	Modified reactive strength index	m·s ⁻¹	VBT vs RIR	16	Difference in PRE-to-POST change	-0.040 [-0.258, 0.179]	-0.111	0.706	1.000
SJ	Relative peak positive power	W·kg ⁻¹	RIR vs PBT	16	Difference in PRE-to-POST change	-0.438 [-4.232, 3.356]	-0.004	0.811	1.000
SJ	Relative peak positive power	W·kg ⁻¹	VBT vs PBT	15	Difference in PRE-to-POST change	1.377 [-4.801, 7.554]	0.086	0.644	1.000
SJ	Relative peak positive power	W·kg ⁻¹	VBT vs RIR	16	Difference in PRE-to-POST change	1.814 [-5.542, 9.171]	0.164	0.610	1.000
SJ	Relative mean propulsive power	W·kg ⁻¹	RIR vs PBT	16	Difference in PRE-to-POST change	0.879 [-2.189, 3.947]	0.208	0.554	1.000
SJ	Relative mean propulsive power	W·kg ⁻¹	VBT vs PBT	15	Difference in PRE-to-POST change	0.037 [-3.215, 3.289]	-0.026	0.981	1.000
SJ	Relative mean propulsive power	W·kg ⁻¹	VBT vs RIR	16	Difference in PRE-to-POST change	-0.842 [-4.629, 2.945]	-0.136	0.645	1.000
SJ	Relative propulsive impulse	N·s·kg ⁻¹	RIR vs PBT	16	Difference in PRE-to-POST change	-0.040 [-0.150, 0.070]	-0.175	0.458	1.000
SJ	Relative propulsive impulse	N·s·kg ⁻¹	VBT vs PBT	15	Difference in PRE-to-POST change	0.031 [-0.215, 0.278]	0.038	0.793	1.000
SJ	Relative propulsive impulse	N·s·kg ⁻¹	VBT vs RIR	16	Difference in PRE-to-POST change	0.071 [-0.187, 0.329]	0.189	0.570	1.000

For relative peak vertical force and mean positive vertical impulse, estimates are geometric mean ratios; all other training-session estimates are mean differences. CMJ and SJ estimates are between-condition differences in PRE-to-POST change. For mean differences, positive estimates indicate a higher value for the first condition named in the contrast; for ratios, values >1 indicate a higher geometric mean for the first condition. CMJ, counter-movement jump; SJ, squat jump; PBT, percentage-based training; RIR, repetitions in reserve; VBT, velocity-based training. pHolm denotes the Holm-adjusted p value.

Table S6. Within-session reliability of countermovement- and squat-jump outcomes.

Jump type	Time point	Outcome	ICC (95% CI)	CV (%)
CMJ	PRE	Jump height	0.969 (0.950 to 0.981)	3.5
CMJ	PRE	Modified reactive strength index (RSI _{mod})	0.928 (0.884 to 0.957)	8.4
CMJ	PRE	Relative peak positive power	0.741 (0.589 to 0.843)	15.3
CMJ	PRE	Relative mean propulsive power	0.975 (0.959 to 0.985)	3.2
CMJ	PRE	Relative propulsive impulse	0.966 (0.945 to 0.980)	1.8
CMJ	POST	Jump height	0.960 (0.933 to 0.977)	4.9
CMJ	POST	Modified reactive strength index (RSI _{mod})	0.873 (0.789 to 0.927)	12.7
CMJ	POST	Relative peak positive power	0.787 (0.651 to 0.876)	13.0
CMJ	POST	Relative mean propulsive power	0.966 (0.944 to 0.980)	4.3
CMJ	POST	Relative propulsive impulse	0.957 (0.929 to 0.975)	2.4
SJ	PRE	Jump height	0.835 (0.734 to 0.901)	9.0
SJ	PRE	Modified reactive strength index (RSI _{mod})	0.759 (0.612 to 0.856)	16.9
SJ	PRE	Relative peak positive power	0.906 (0.849 to 0.944)	5.7
SJ	PRE	Relative mean propulsive power	0.682 (0.489 to 0.810)	15.4
SJ	PRE	Relative propulsive impulse	0.841 (0.744 to 0.905)	4.5
SJ	POST	Jump height	0.760 (0.610 to 0.859)	10.6
SJ	POST	Modified reactive strength index (RSI _{mod})	0.621 (0.385 to 0.777)	19.7
SJ	POST	Relative peak positive power	0.871 (0.790 to 0.924)	6.6
SJ	POST	Relative mean propulsive power	0.398 (0.026 to 0.645)	18.6
SJ	POST	Relative propulsive impulse	0.774 (0.633 to 0.867)	5.0

Abbreviations: CMJ, countermovement jump; SJ, squat jump; ICC, intraclass correlation coefficient; CV, coefficient of variation; PRE, preexercise; POST, postexercise.