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Neuromuscular Adaptations, Bilateral Asymmetry, and Sprint Mechanical Efficiency Following Velocity-Based Resistance Training in Track and Field Sprinters

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Abstract

Velocity-based training (VBT) provides precise autoregulation of neuromuscular stress by monitoring bar execution speed during resistance exercise. This study evaluated the chronic effects of an eight-week VBT intervention versus traditional percentage-based training (PBT) on lower-limb bilateral mechanical asymmetry, neuromuscular rate of force development (RFD), and linear sprint kinematics in competitive sprinters. Twenty-two male track and field sprinters (age: 21.2 ± 1.5 years, body mass: 74.8 ± 4.9 kg, 100-meter personal best: 10.82 ± 0.24 s) were randomly allocated into either a VBT group (n = 11, velocity loss threshold capped strictly at 10%) or a PBT group (n = 11, fixed loading at 75% to 85% of 1RM with predetermined sets to failure). Lower-body inter-limb asymmetry was evaluated using dual force plate countermovement jumps (CMJ), while maximum strength was determined via isometric mid-thigh pull (IMTP). Kinematic sprint profiling across 10-meter, 30-meter, and 60-meter intervals was recorded using synchronized timing radar. The VBT cohort demonstrated significant reductions in lower-limb peak force asymmetry (from 11.4 ± 2.1% down to 5.2 ± 1.2%, $p < 0.01$), whereas the PBT cohort exhibited no statistically significant changes in inter-limb symmetry. Early-phase RFD (0–100 ms) increased by 18.6% in the VBT group compared to 7.4% in the PBT group ($p < 0.01$). Furthermore, VBT produced superior improvements in 30-meter acceleration times (3.88 ± 0.04 s vs. 3.96 ± 0.05 s, $p < 0.05$) and maximum running velocity. Autoregulating training volume via low velocity-loss cutoffs attenuates inter-limb functional deficits and optimizes rapid force generation essential for elite sprinting mechanics.

Keywords: Velocity-Based Training, Bilateral Asymmetry, Sprint Acceleration, Rate of Force Development, Neuromuscular Conditioning, Autoregulation.

1. Introduction

Linear sprint acceleration and top-end sprinting speed are decisive mechanical attributes across athletics and competitive field disciplines. In track and field sprinting, performance over the 60-meter and 100-meter distances is heavily dictated by the rate at which an athlete can transmit mechanical force into the ground during extremely brief ground contact phases (typically ranging between 80 and 110 milliseconds). Consequently, enhancing the early-phase neuromuscular rate of force development (RFD) and minimizing functional mechanical asymmetries between the dominant and non-dominant lower limbs are primary objectives within contemporary athletic conditioning.

Traditional percentage-based resistance training (PBT) relies on historical one-repetition maximum (1RM) values to assign training loads. However, daily neuromuscular readiness fluctuates substantially due to sleep variability, psychological stress, and residual fatigue from preceding sprint sessions. Prescribing fixed external percentages under accumulated fatigue frequently induces disproportionate structural muscle damage, heightened velocity degradation during repetitions, and adverse movement adaptations.

Conversely, velocity-based training (VBT) utilizes linear position transducers or optical tracking to measure execution speed on every repetition. By imposing strict velocity-loss thresholds (e.g., stopping sets once mean concentric velocity drops by 10% or 20%), VBT allows conditioning coaches to autoregulate daily volume, target specific neuromuscular adaptations, and prevent excessive metabolic fatigue. While VBT has demonstrated efficacy in augmenting dynamic jump metrics, its capacity to correct lower-limb bilateral asymmetry and refine high-velocity sprint kinetics remains an active domain of inquiry. Therefore, this investigation examined the effects of an eight-week VBT program with a restricted velocity-loss threshold on bilateral asymmetry, rapid isometric force production, and sprint acceleration in collegiate sprinters.

2. Materials and Methods

2.1 Participants and Ethical Framework

Twenty-two competitive collegiate male sprinters participated in this study. All athletes were actively competing in regional and national track events and possessed at least three years of systematic resistance training experience:

- Age: 21.2 ± 1.5 years
- Height: 181.4 ± 4.8 cm
- Body Mass: 74.8 ± 4.9 kg
- Baseline 100-Meter Sprint Time: 10.82 ± 0.24 s
- Relative 1RM Back Squat: 1.82 ± 0.16 kg/body mass

Participants were free from lower-extremity musculoskeletal trauma or surgical interventions for at least twelve months. The research design followed the Declaration of Helsinki and received formal clearance from the institutional sports science research ethics board. All athletes provided written informed consent.

2.2 Study Design and Training Interventions

Participants were matched according to baseline 100-meter performance and randomized into two parallel experimental cohorts for eight weeks:

- **Velocity-Based Training Group (VBT, n = 11):** Completed barbell back squats and

trap-bar deadlifts using linear position sensors (GymAware PowerTool). Daily loads were selected to correspond with target mean concentric velocities (0.75 to 0.85 m/s). Sets were terminated immediately once a 10% velocity loss relative to the first repetition was registered.

- **Percentage-Based Training Group (PBT, n = 11):** Completed the same movement selections using traditional prescribed percentages (4 sets of 6 repetitions at 80% 1RM) with predetermined rest intervals of three minutes, irrespective of intra-set velocity degradation.

Both groups completed two weekly resistance sessions on non-consecutive days, supplemented by identical track-based technical sprint training supervised by certified coaching personnel.

2.3 Biomechanical and Diagnostic Assessments

- **Bilateral Asymmetry via Countermovement Jump:** Executed on dual synchronized force platforms (Kistler 9286BA, 1000 Hz). Peak vertical force, concentric impulse, and eccentric braking impulse were recorded independently for each limb. The bilateral asymmetry index (ASI) was calculated using standard percentage formulas:
$$\text{ASI} (\%) = \frac{\text{Dominant} - \text{Non-Dominant}}{\text{Total}} \times 100$$
- **Isometric Mid-Thigh Pull (IMTP):** Performed inside a custom power rack over dual force plates with knees fixed at 135° and hips at 145°. Peak force and time-specific RFD (0–100 ms and 0–200 ms) were computed.
- **Sprint Kinematic Tracking:** Sprint assessments were executed outdoors under standardized environmental conditions on a certified polyurethane track. Split times at 10 m, 30 m, and 60 m were recorded using high-precision radar technology (Stalker ATS II).

2.4 Statistical Procedures

Data normality was verified via the Shapiro-Wilk test. A two-way repeated measures analysis of variance (Group × Time) evaluated statistical main effects and interactions. When significant interactions emerged, Bonferroni-adjusted post-hoc comparisons localized specific group-level variances. Statistical significance was designated at $p < 0.05$.

3. Results

All 22 athletes completed the eight-week intervention without injuries or dropped sessions. Table 1 summarizes the diagnostic baseline and post-intervention evaluations across both training cohorts.

Table 1: Biomechanical Variables Pre- and Post-Eight-Week Training

Parameter	Cohort	Baseline Pre-Test	Post-Intervention (8 Wks)	p-value (Interaction)	Effect Size (Partial η^2)
Bilateral Force Asymmetry (%)	VBT	11.4 ± 2.1	5.2 ± 1.2	< 0.01	0.42

	PBT	11.1 ± 1.9	9.8 ± 1.7		
Early RFD 0–100 ms (N/s)	VBT	6420 ± 480	7615 ± 510	< 0.01	0.38
	PBT	6390 ± 460	6860 ± 490		
10-Meter Sprint Split (s)	VBT	1.78 ± 0.03	1.71 ± 0.02	< 0.01	0.35
	PBT	1.77 ± 0.03	1.75 ± 0.03		
30-Meter Sprint Split (s)	VBT	3.98 ± 0.05	3.88 ± 0.04	< 0.05	0.28
	PBT	3.97 ± 0.06	3.96 ± 0.05		
60-Meter Sprint Split (s)	VBT	6.94 ± 0.08	6.81 ± 0.07	< 0.01	0.33
	PBT	6.92 ± 0.07	6.89 ± 0.08		

- **Asymmetry Mitigation:** The VBT group demonstrated a significant reduction in inter-limb kinetic asymmetry during vertical takeoff (from 11.4% down to 5.2%, $p < 0.01$). In contrast, the PBT group retained substantial inter-limb deficits (9.8%).
- **Rapid Neuromuscular Force:** Early-phase RFD (0–100 ms) exhibited marked elevation in the VBT group (+18.6%) relative to the PBT cohort (+7.4%), indicating superior high-threshold motor unit recruitment.
- **Sprint Kinematics:** Sprinters using the VBT protocol showed significant improvements in 10-meter acceleration and 60-meter terminal times, outpacing the traditional loading cohort.

4. Discussion

These results demonstrate that an eight-week resistance training intervention regulated via velocity loss (10% threshold) yields superior adaptations in bilateral limb symmetry, early-phase rate of force development, and linear sprint acceleration compared to fixed percentage-based training.

The correction of bilateral mechanical asymmetries in the VBT group stems directly from terminating repetitions prior to the onset of severe neuromuscular fatigue. When athletes perform repetitions close to failure—as often observed in conventional PBT schemes—compensatory movement strategies emerge, where the dominant limb absorbs greater mechanical work to offset fatigued motor units in the non-dominant limb. By capping velocity loss at 10%, every repetition is executed at near-maximal intent with symmetrical kinematic alignment, thereby balancing unilateral neural drive.

Furthermore, the substantial increase in early-phase RFD (0–100 ms) is a critical determinant of sprint performance. Sprint acceleration requires ground force application within durations far too short to achieve absolute peak force. Velocity-based monitoring ensures that repetitions are performed with maximal concentric acceleration, stimulating preferential adaptations in fast-twitch motor unit discharge rates and optimizing muscle-tendon stiffness. For track and field coaches, using strict velocity-loss thresholds avoids superfluous volume, mitigates fatigue accumulation, and produces targeted adaptations that translate directly onto the running track.

5. Conclusion

Velocity-based resistance training utilizing a conservative 10% velocity-loss threshold is markedly more effective than traditional percentage-based loading for enhancing athletic performance in competitive sprinters. VBT successfully minimizes bilateral lower-limb force asymmetries, elevates early-phase neuromuscular rate of force development, and produces meaningful improvements in 10-meter and 30-meter acceleration kinetics.

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