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The effects of velocity-based vs. percentage-based resistance training on sports performance in trained individuals: a systematic review and meta-analysis

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Abstract

Background This meta-analysis compared the effects of velocity-based training (VBT) and traditional percentage-based training (PBT) on athletic performance, specifically in muscle strength, jump performance, sprint performance, and change-of-direction ability.

Methodology Random-effects models in R were employed for the meta-analysis, and study quality was assessed using the Physiotherapy Evidence Database (PEDro) scale.

Results A total of 17 studies with 348 participants were included in the analysis. The results revealed that VBT produced small but significant improvements in jump performance (SMD = 0.27, 95% CI: [0.03, 0.51], $p < 0.05$) and change-of-direction ability (SMD = 0.45, 95% CI: [0.17, 0.73], $p < 0.01$) compared to PBT. However, no significant differences were found in maximal strength (SMD = 0.21, 95% CI: [-0.01, 0.43], $p = 0.064$) or sprint performance (SMD = 0.14, 95% CI: [-0.11, 0.39], $p = 0.269$).

Conclusions VBT shows small but significant advantages over PBT in improving jump performance and change-of-direction ability. Both methods exhibit similar effects on maximal strength and sprint performance. These findings support implementing VBT for sports requiring rapid force production and directional changes.

Trial registration The prospero registration number: CRD420251020164.

Keywords Velocity-based training, Percentage-based training, Muscle strength, Explosive power, Agility

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Introduction

Resistance training is a fundamental approach to enhancing athletic performance and plays a crucial role in the development of strength, speed, power output, and agility [1–3]. Traditional resistance training typically determines loads based on a fixed percentage of one-repetition maximum (1RM), an approach that is widely adopted and empirically supported [4, 5]. However, the physiological state of athletes is subject to fluctuations due to factors such as training-induced fatigue, nutritional intake, and sleep quality, resulting in variations in 1RM of up to 36% [6, 7]. As a result, percentage-based loading strategies may not accurately match an athlete's actual capacity, potentially compromising training adaptations and increasing the risk of injury [8]. Accordingly, recent research has increasingly emphasized dynamically regulated resistance training strategies to optimize load prescription and improve athletic performance.

With advancements in commercialized velocity-tracking technology, velocity-based training (VBT) has gained increasing recognition as a load-regulation strategy in resistance training [7]. Unlike traditional periodized training (PBT), which follows a fixed progression of load and volume based on predetermined cycles, VBT dynamically adjusts training loads in real-time using concentric movement velocity and instantaneous feedback, allowing for more precise alignment with an athlete's current physiological state [9]. As resistance training progresses, neuromuscular fatigue accumulates with each repetition, leading to a decline in movement velocity. To regulate training intensity, VBT primarily employs velocity zones and velocity loss (VL) thresholds as key strategies. Velocity zones are predefined ranges of concentric velocity (e.g., 0.50–0.60 m/s) based on an individual's load-velocity profile, guiding athletes to train within specific velocity ranges to maintain optimal intensity for their goals [10]. Velocity loss (VL) refers to the percentage decrease in velocity during a set, with thresholds (e.g., 10% or 20%) signaling when to terminate or adjust the set due to fatigue accumulation [11]. While velocity zones focus on maintaining consistent velocity ranges to optimize load, VL thresholds monitor fatigue to adjust intensity, offering a more individualized approach to volume regulation. Compared to PBT, VBT's dynamic, real-time adjustments in intensity may enhance power output and reduce excessive fatigue, thereby potentially leading to more favorable training adaptations and long-term athletic performance [12, 13].

Although interest in VBT has grown rapidly and its advantages in training regulation have been increasingly emphasized, current evidence regarding its superiority over PBT remains inconsistent and inconclusive [10, 11]. The existing literature presents inconsistent findings regarding their comparative efficacy. While some studies

suggest that VBT enhances strength, explosive power, and athletic performance [14, 15], others report no significant differences [8, 16], and in certain contexts, PBT has demonstrated superior outcomes [17]. To clarify these discrepancies, several meta-analyses have compared VBT and PBT but are limited by small sample sizes and methodological issues. The meta-analyses by Liao et al. [18] and Orange et al. [19] included only 4 and 6 studies, respectively, limiting their statistical power and generalizability. Another network meta-analysis conducted by Held et al. [20] expanded the scope of comparison but included only four direct or indirect studies comparing VBT and PBT, with considerable methodological heterogeneity. More recently, Jing et al. [21] conducted a broader meta-analysis focused on muscle strength, and Zhang et al. [22] examined dose–response relationships of key VBT variables such as velocity loss thresholds and load prescriptions. Despite these advances, most analyses focus on single performance outcomes and lack a comprehensive synthesis across multiple domains including strength, speed, agility, and athletic performance. Consequently, a comprehensive, high-quality meta-analysis is needed to better elucidate the comparative efficacy of VBT and PBT across diverse performance metrics.

This systematic review and meta-analysis aims to comprehensively compare the effects of VBT and PBT on athletic performance, focusing on maximal strength, jump performance, sprint speed, and change-of-direction ability. It is hypothesized that VBT produces greater improvements in jump performance, sprint speed, and change-of-direction ability, while both VBT and PBT yield comparable gains in maximal strength.

Materials and methods

This systematic review and meta-analysis complied with PRISMA guidelines [23] was prospectively registered in PROSPERO (CRD420251020164).

Search strategy and study selection

A comprehensive literature search was conducted in PubMed, Web of Science, Scopus, SPORTDiscus, and CNKI up to March 2025. The search strategy was developed using Boolean operators (AND, OR) to combine relevant keywords across three domains: (1) velocity-based training (e.g., “velocity-based training,” “VBT,” “velocity training,” “load velocity profile,” “velocity loss,” “VL”); (2) resistance training modalities (e.g., “percentage-based training,” “resistance training,” “strength training,” “weight training”); and (3) performance outcomes (e.g., “strength,” “one repetition maximum,” “1RM,” “jump,” “speed,” “sprint,” “change of direction,” “agility”). An example of the search strategy used in Web of Science is as follows: [Topic] (“velocity-based training” OR “VBT” OR “velocity training” OR “load velocity profile” OR

“velocity loss” OR “VL”) AND [Topic] (“Percentage-Based Training” OR “resistance training” OR “strength training” OR “weight training”) AND [Topic] (“strength” OR “one repetition maximum” OR “1RM” OR “jump” OR “speed” OR “sprint” OR “change of direction” OR “agility”). The detailed search strategy is provided in Supplementary File 1. After removing duplicates, studies were screened based on titles and keywords, followed by full-text assessment. Additionally, reference lists of relevant systematic reviews and primary studies were manually screened to identify further eligible studies. The study selection process is illustrated in Fig. 1, with screening independently conducted by two researchers and discrepancies resolved by a third researcher.

Eligibility criteria

Studies eligible for inclusion were required to meet the following Population, Intervention, Comparator, Outcomes, and Study design (PICOS) criteria: Healthy individuals aged ≥ 16 years with at least six months of

documented resistance training experience (P); implemented VBT as the intervention and PBT as the comparator, with interventions lasting at least four weeks (I and C); measured outcomes including maximal strength, jump performance, sprint performance, or change-of-direction ability (O); and included randomized controlled trials or controlled trials (S).

Methodological quality assessment and risk of bias

Methodological quality was assessed using the Physiotherapy Evidence Database (PEDro) scale, primarily evaluating randomization, blinding, and outcome reporting [24]. According to established research standards [25], studies scoring 6–10 were classified as high quality, 4–5 as moderate quality, and < 4 as low quality. In addition, the overall quality of evidence for each outcome was evaluated using the GRADE approach, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias [26, 27]. Risk of bias was assessed using a funnel plot and Egger’s test to detect potential

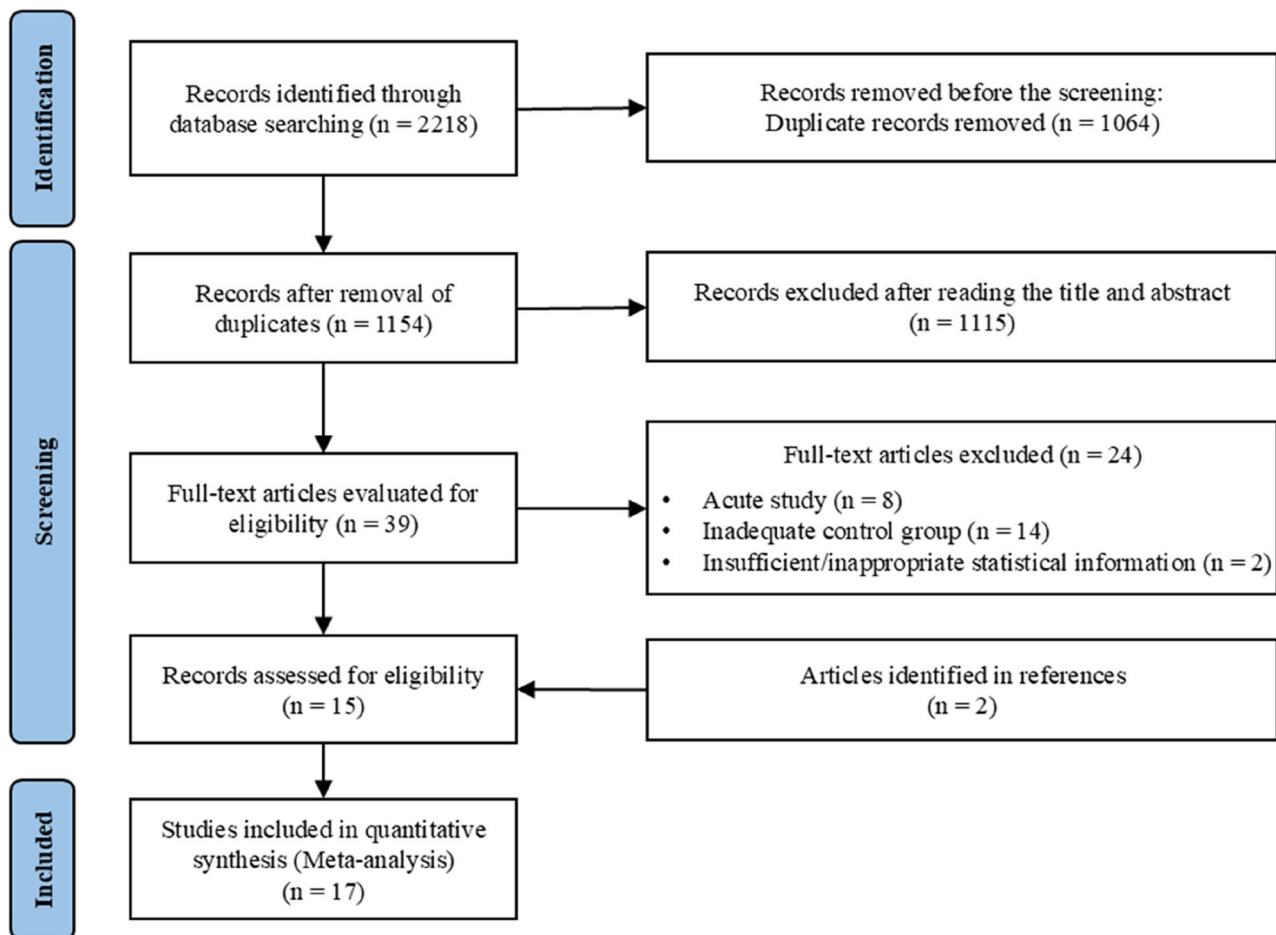


Fig. 1 PRISMA flow diagram

publication bias. Sensitivity analyses were conducted to evaluate the stability of the results and the influence of individual studies.

Data extraction

Extracted data included participant characteristics such as age, sex, sport discipline, training experience, and sport level, along with training program details such as protocol, intensity, VBT velocity or VL, training duration, and frequency. Additionally, training outcomes were recorded, including maximal strength (isometric or isokinetic), jump performance (e.g., countermovement jump, squat jump, single-leg jump), sprint performance (e.g., 5–30 m sprint), and change-of-direction ability (e.g., 505 change-of-direction test, T-test). Detailed extracted data are presented in Table 1.

Statistical analyses

Meta-analyses were conducted using R (version 4.3.0). A random-effects model was applied to synthesize effect sizes for maximal strength, jump performance, sprint performance, and change-of-direction ability. Effect size was computed based on pre-to-post intervention changes in means and standard deviations to minimize potential bias arising from baseline differences [39]. The change in standard deviation was determined using the following formula:

$$SD_{change} = \sqrt{(SD_{pre}^2/N_{pre}) + (SD_{post}^2/N_{post})}$$

Standardized mean differences were used to quantify effect sizes, categorized as trivial (< 0.2), small (0.2–0.5), moderate (0.5–0.8), and large (> 0.8) [40]. Although SMD < 0.2 is statistically trivial, even small effects may be meaningful in exercise and sports settings [41]. Statistical heterogeneity was assessed using the I^2 statistic, with thresholds of < 25% indicating low, 25%–75% moderate, and \geq 75% high heterogeneity [42]. Statistical significance was set at $p < 0.05$.

Results

Study selection

A total of 2,218 records were initially retrieved from five databases. After removing duplicates, 1,154 records remained. Following title and abstract screening, 39 studies were selected for full-text review, of which 15 met the inclusion criteria. The references for the 24 excluded studies are provided in Supplementary File 2. Two additional studies were identified through reference list screening of key systematic reviews and relevant studies. In total, 17 studies were included in the meta-analysis. The study selection process is detailed in Fig. 1.

Methodological quality assessment and risk of bias

The PEDro assessment revealed that three studies were of moderate quality and fourteen were of high quality, with a median score of 6 out of 10, indicating an overall moderate-to-high methodological quality (Supplementary Material 3). The overall quality of evidence for maximal strength, jump performance, sprint performance, and change-of-direction ability was rated as moderate using the GRADE approach (Supplementary Material 4). Egger's test revealed no significant publication bias for maximal strength ($b = 1.96$, $t = 1.21$, $p = 0.24$), jump performance ($b = 0.80$, $t = 0.65$, $p = 0.53$), sprint performance ($b = 1.47$, $t = 0.75$, $p = 0.47$), or change-of-direction ability ($b = 2.30$, $t = 1.23$, $p = 0.25$). Furthermore, the funnel plot exhibited a fairly uniform distribution, further supporting the lack of significant publication bias (Supplementary Material 5). Sensitivity analyses confirmed the robustness of the results, with no significant changes in effect sizes (Supplementary Material 6).

Meta-analysis results

This meta-analysis included 17 studies with 348 participants, comparing the effects of VBT and PBT on maximal strength (Fig. 2). The results showed no significant difference between VBT and PBT in maximal strength (SMD = 0.21, 95% CI: [-0.01, 0.43], $p = 0.064$, $I^2 = 0\%$). For jump performance, 14 studies with 286 participants indicated a small but significant improvement with VBT compared to PBT (SMD = 0.27, 95% CI: [0.03, 0.51], $p = 0.029 < 0.05$, $I^2 = 0\%$) (Fig. 3). In contrast, 12 studies with 24 participants found no significant difference between VBT and PBT in sprint performance (SMD = 0.14, 95% CI: [-0.11, 0.39], $p = 0.269$, $I^2 = 0\%$) (Fig. 4). Notably, 9 studies with 197 participants demonstrated that VBT had a moderate advantage over PBT in change-of-direction ability (SMD = 0.45, 95% CI: [0.17, 0.73], $p = 0.002 < 0.01$, $I^2 = 0\%$) (Fig. 5). Given the low heterogeneity ($I^2 = 0\%$), subgroup analyses were not conducted, as the results demonstrated a high degree of consistency across studies.

Discussion

This meta-analysis synthesized evidence from 17 studies comparing VBT with PBT, comprising 10 studies published after 2022 and 7 earlier studies, which is notably more than the 4–8 studies included in previous meta-analyses [18–21]. The larger dataset in the present review reflects both the rapid growth of VBT research and the use of broader yet rigorous inclusion criteria that emphasized randomized or quasi-experimental designs, standardized outcome measures, and detailed reporting of training variables. This expansion improved statistical power and provided a more comprehensive evaluation of modern VBT practices.

Table 1 The characteristics of the included studies

Studies	Subjects; N	Age (years)	Training Program	PBT Intensity	VBT Mean Velocity	VBT Load Adjustment	Duration; Frequency	Outcome measures
Banyard 2020 [28]	Resistance trained males; 24	25.9 ± 5.1	Back squat: 5 sets × 5 reps; 2-minute interset recovery; velocity monitored via velocity sensor	59–85% 1RM	0.62–0.89 m/s	± 5% 1RM if MV > ± 0.06 m/s	6 wk 3 times/wk	Back squat, 5–20 m sprint, COD
Chen 2022 [29]	Male sprinter; 20	20.4 ± 1.3	Back squat: 4 sets × 4 reps; 2–3 min interset recovery; velocity monitored via Tendo Unit	80% 1RM	0.54 m/s	± 5% 1RM if MV > ± 0.05 m/s	6 wk 2 times/wk	Back squat, CMJ, 20 m sprint, COD
Dorrell 2020 [30]	Resistance trained males; 16	22.8 ± 4.5	Back squat, bench press, strict overhead press, and deadlift: 3 sets × 3–8 reps; 2–3 min interset recovery; velocity monitored via Tendo Unit	70–95% 1RM	0.74–0.88 m/s	20% VL via load-velocity curve	6 wk 2 times/wk	Back squat, bench press, strict overhead press, deadlift, CMJ
Held 2021 [14]	Rowers; 21	19.6 ± 2.0	Power clean, back squat, bench row, deadlift, bench press: 4 sets, 2–3 min inter-set recovery	80% 1RM	NG	10% VL via load-velocity curve	8 wk 2 times/wk	Back squat
Jiménez-Reyes 2021 [17]	Male sport sciences students; 24	23.1 ± 4.1	Squat: 3 sets × 3–8 reps; 4-minute interset recovery; velocity monitored via velocity sensor	50–80% 1RM	0.68–1.13 m/s	± 1% 1RM if MV > ± 0.03 m/s	8 wk 2 times/wk	Back squat, CMJ, 10–20 m sprint
Kong 2022 [31]	Female volleyball players; 12	19.0 ± 1.4	Back squat: 6 sets × 4 reps; 3-minute interset recovery; velocity monitored via Tendo Unit	80% 1RM	0.50–0.60 m/s	+ 5% 1RM if > 0.61 m/s; – 5% 1RM if < 0.50 m/s	8 wk 2 times/wk	Back squat, CMJ, 30 m sprint, COD
Liu 2024 [16]	Swimmers; 8	19.3 ± 0.5	Back squat: 50 min intervention; velocity monitored via GymAware sensor	75% 1RM	MV at 75% 1RM	± 5% 1RM if MV > ± 0.06 m/s	8 wk 3 times/wk	Back squat, CMJ, SJ, 30 m sprint
Lu 2025 [15]	Badminton players; 20	19.3 ± 1.2	Back squat: 4 sets × 8 reps; velocity monitored via Younova VBRT system	65–95% 1RM	MV at 65–95% 1RM	± 5% 1RM if MV > ± 0.06 m/s; 10% VL	6 wk 2 times/wk	Back squat, CMJ, SJ, SLJ, COD
Montalvo-Pérez 2021 [32]	Female cyclists; 17	26.0 ± 7.0	Squat, hip thrust, and split squat: 3 sets × 4–8 reps; 2–3 min interset recovery; velocity monitored via RPE	80–90% 1RM	NG	If power < 90% Maximal Power Point	6 wk 2 times/wk	Squat, hip thrust, split squat
Orange 2019 [13]	Male rugby players; 27	17.0 ± 1.0	Back squat, deadlift: 3 sets × 7 reps; 2-minute interset recovery; velocity monitored via GymAware sensor	60–80% 1RM	MV at 60–80% 1RM	± 5% 1RM if MV > ± 0.06 m/s	7 wk 2 times/wk	Back squat, CMJ, 5–30 m sprint
Rossi 2024 [8]	Resistance trained females; 20	22.7 ± 0.8	Squat, squat-jump, bench press, push-up, and lunges: Wave periodization structure, adjusting relative load, sets, and rest intervals; velocity monitored via GymAware sensor	70–95% 1RM	MV at 70–95% 1RM	10% VL via load-velocity curve	6 wk 2 times/wk	Squat, CMJ, SJ, 5–20 m sprint, COD
Sekulovic 2024 [33]	Youth male soccer players; 34	18.2 ± 0.7	Back squat, bench press, and deadlift: 3 sets × 6–10 reps; velocity monitored via velocity sensor	60–80% 1RM	0.72–0.86 m/s	± 1% 1RM if MV > ± 0.06 m/s; 15%, 30% VL	4 wk 2 times/wk	Back squat, CMJ, 20 m sprint, COD
Shao 2024 [34]	Male sanda fighters; 20	16.6 ± 0.8	Back squat, bench press, and deadlift: 3 sets × 6–10 reps; 2-minute interset recovery	75% 1RM	0.5 m/s	Via load-velocity curve	6 wk 2 times/wk	Back squat, 30 m sprint
Vasiljevic 2024 [35]	Male sports science student; 32	21.2 ± 0.8	Back squat and bench press: Wave periodization structure, adjusting relative load, sets, and rest intervals; velocity monitored via Linear Position Transducer	70–95% 1RM	MV at 70–95% 1RM	Via load-velocity curve	6 wk 2 times/wk	Back squat, CMJ, COD
Wang 2020 [36]	Male basketball players; 20	20.1 ± 0.9	Back squat: 4 sets × 6 reps; 2-minute interset recovery; velocity monitored via GymAware sensor	75% 1RM	MV at 75% 1RM	Via load-velocity curve	8 wk 2 times/wk	Back squat, jump, 10 m sprint, COD

Table 1 (continued)

Studies	Subjects; N	Age (years)	Training Program	PBT Intensity	VBT Mean Velocity	VBT Load Adjustment	Duration; Frequency	Outcome measures
Zhang 2023a [37]	Female basketball players; 15	21.9 ± 2.0	Back squat and bench press: 4 sets × 3–12 reps; 1.5–2.5 min intersets; recovery: velocity monitored via GymAware sensor	65–95% 1RM	0.38–0.8 m/s	± 5% 1RM if MV > ± 0.06 m/s	6 wk 2 times/wk	Back squat, CMJ, SJ, DJ, SLG, 10–20 m sprint, COD
Zhang 2023b [38]	Female basketball players; 18	22.3 ± 1.8	Back squat and bench press: 3 sets; 3-minute intersets; recovery: velocity monitored via GymAware sensor	65–95% 1RM	MV at 60–95% 1RM	± 5% 1RM if MV > ± 0.06 m/s	6 wk 2 times/wk	CMJ, 30 m sprint

CMJ counter movement jump, COD change of direction, DJ drop jump, MV mean velocity, SJ squat jump, SLJ standing long jump, VL velocity loss

The findings demonstrate that VBT showed small but significant advantages over PBT in improving jump performance and change of direction ability, while both approaches yield comparable gains in maximal strength and sprint performance. Moreover, subgroup analyses revealed that these effects were consistent across age groups, sexes, sport levels, and training durations, indicating the broad applicability of VBT’s benefits. However, it is important to note that the majority of studies included in this meta-analysis employed relatively short intervention durations (≤ 8 weeks), which may have limited the expression of neuromuscular adaptations, highlighting the need for longer intervention periods in future research.

Muscle strength

This meta-analysis found no significant differences between VBT and PBT in maximal strength gains, with a small overall effect size (SMD = 0.21, 95% CI: [-0.01, 0.43], *p* = 0.06) and low heterogeneity (*I*² = 0%), consistent with previous meta-analyses [18, 19]. These findings suggest that both training modalities are equally effective in promoting strength when total training volume and target intensity ranges are matched, despite velocity-based load adjustments in VBT.

VBT regulates training loads through velocity feedback, maintaining movement efficiency and technical execution, whereas PBT follows a fixed-load progression, prioritizing absolute load increments [9]. Although VBT generally involves lower absolute training loads than PBT, its focus on high-velocity execution may compensate for this difference by promoting greater power output and enhancing fast-twitch fiber recruitment. Such high-velocity stimuli provide sufficient neuromuscular activation to support strength adaptation even under reduced loading [43, 44]. Consequently, despite lower external loads, VBT achieves strength gains comparable to those of PBT.

The selection of velocity loss thresholds in VBT can significantly influence training load accumulation and adaptation outcomes [45]. Most of the included studies employed velocity loss thresholds between 10% and 30%, or absolute velocity deviations of ± 0.06–0.12 m/s, which for back squat exercises generally correspond to a 10–30% velocity loss range [11]. These relatively modest velocity losses effectively maintain movement velocity and minimize fatigue, likely contributing to the comparable strength gains observed between VBT and PBT when training volume and intensity were matched in this meta-analysis. Recent meta-analyses have identified the 10–30% velocity loss range as effective for improving one-repetition maximum strength, likely due to its balance between neural activation and hypertrophic stimulus [45, 46]. However, as studies employing velocity loss

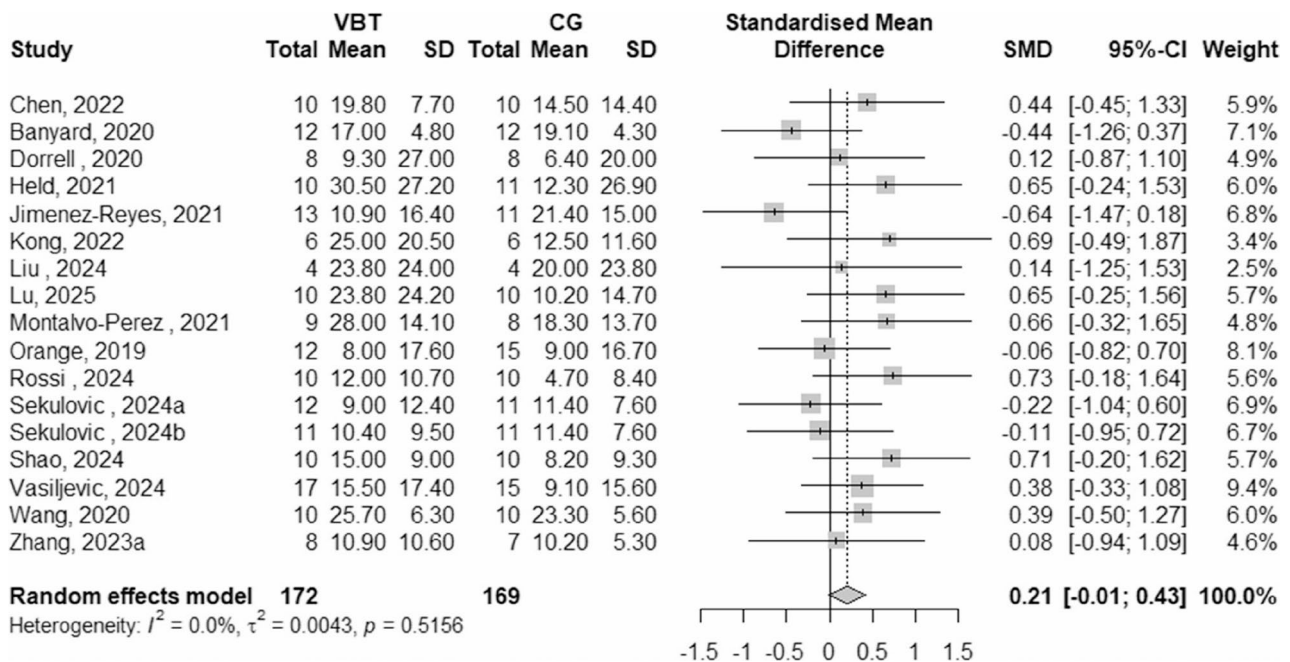


Fig. 2 Forest plot of the results for strength performance

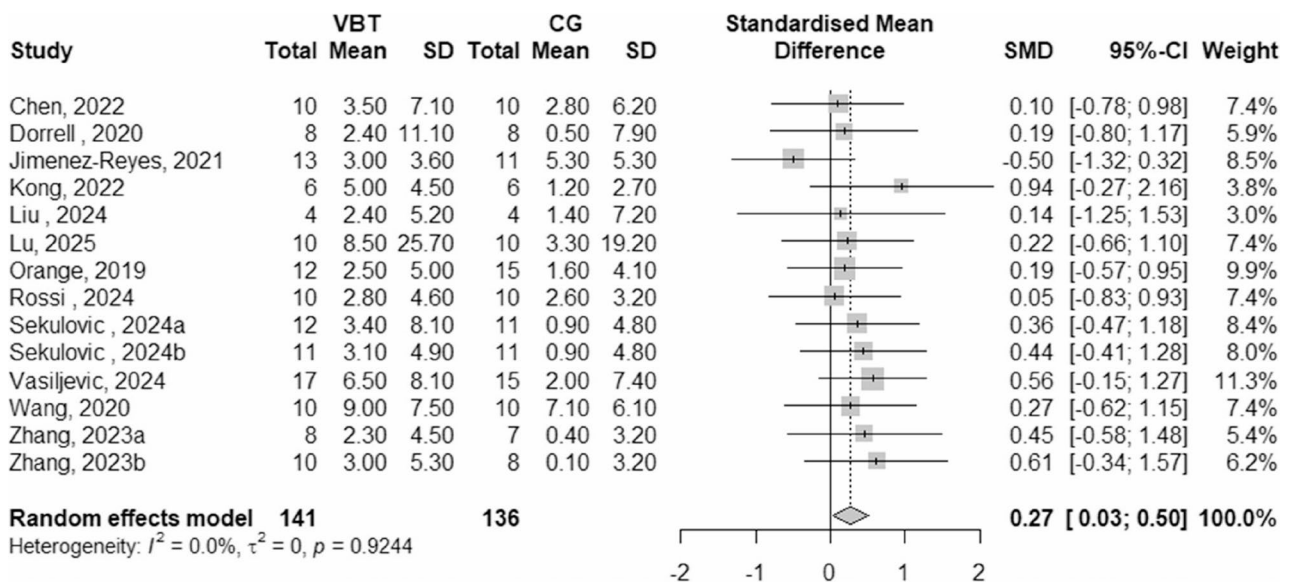


Fig. 3 Forest plot of the results for jump performance

thresholds above 30% were not included in this meta-analysis, it remains unclear whether higher thresholds would yield additional benefits. Greater fatigue accumulation at higher velocity losses could shift VBT training characteristics closer to traditional PBT, potentially diminishing its velocity-specific advantages [11]. Future research should clarify how varying velocity loss thresholds influence strength adaptations and fatigue, particularly beyond the commonly studied 10–30% range, to optimize VBT programming.

Jump performance

This meta-analysis found that VBT resulted in significantly greater improvements in jump performance compared to PBT, with a small effect size (SMD = 0.27, 95% CI: [0.03, 0.51], $p < 0.05$) and low heterogeneity ($I^2 = 0\%$). These findings contrast with earlier meta-analyses [18, 19], which reported no significant difference between the two methods. The discrepancy is likely due to differences in sample size and study design, as previous reviews included fewer studies, limiting statistical power and controlling for training variables.

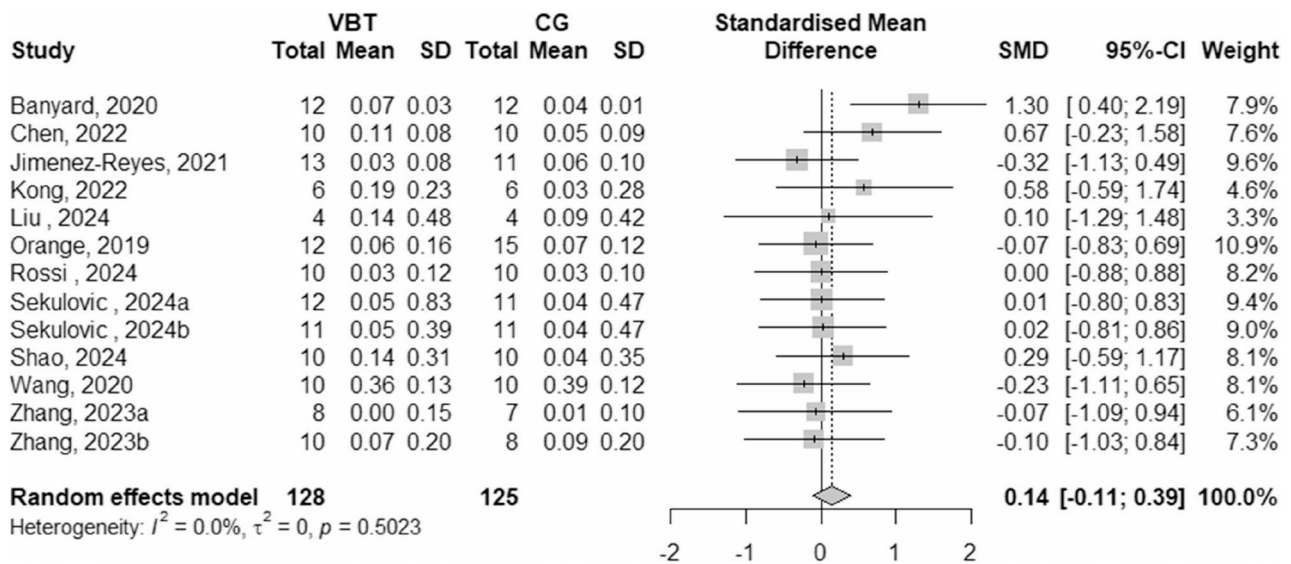


Fig. 4 Forest plot of the results for sprint performance

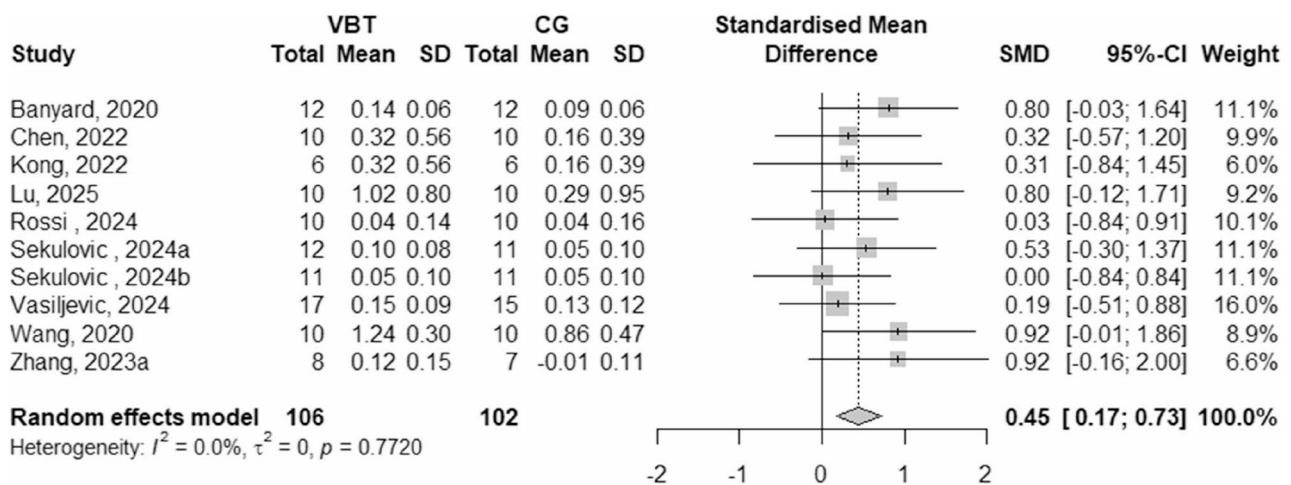


Fig. 5 Forest plot of the results for change of direction

Previous research has emphasized the critical role of neuromuscular factors such as motor unit recruitment, muscle fiber composition, and the effectiveness of the stretch-shortening cycle in determining vertical jump performance [47]. The neuromuscular adaptations triggered by VBT are particularly beneficial for improving these key factors. VBT, with its focus on high velocity and low training loads, enhances neuromuscular drive by maximizing motor unit recruitment, increasing rate coding, and optimizing muscle fiber activation, particularly within the fast-twitch fibers responsible for explosive power [18, 43, 48]. This, in turn, improves SSC efficiency, which is a critical determinant of jump performance. The eccentric phase of SSC, where the muscle lengthens, and the concentric phase, where the muscle shortens, are both more effective when high-speed training is integrated, facilitating faster force development and

improving reactive strength [44, 49]. In contrast, muscle failure training in PBT can lead to unnecessary fatigue, producing suboptimal training stimuli that predominantly target slower, endurance-type muscle fibers, thus potentially impairing the speed of strength development [11]. Additionally, squats, which were the primary exercise used in most of the studies included in this meta-analysis (94.1%), share biomechanical similarities with jump performance (e.g., CMJ). While executing high-load, high-speed repetitions in squats is more challenging than performing jumps, VBT's emphasis on maximal voluntary effort and high movement velocity likely facilitates a better transfer of these adaptations to jump performance, making VBT more advantageous than PBT in improving jump performance. These findings suggest that athletes aiming to improve jump performance should prioritize velocity-controlled training, particularly

vertical-specific exercises, to optimize neuromuscular adaptations for explosive power development.

Sprint performance

Interestingly, no significant differences were observed between VBT and PBT in improving sprint performance, with a small effect size (SMD = 0.14, 95% CI: [-0.11, 0.39], $p = 0.27$) and low heterogeneity ($I^2 = 0\%$). Previous research has demonstrated a strong correlation between maximal squat strength and sprint performance ($r = -0.77$, $p = 0.001$) [50]. The similar improvements in strength observed between VBT and PBT may help explain the lack of significant differences in sprint performance in this meta-analysis. Furthermore, the principle of training specificity suggests that the absence of linear sprint training and horizontally oriented resistance exercises in the intervention protocols likely limited the transfer of training effects to sprinting [11]. Additionally, the relatively short training durations (typically less than 8 weeks) in most of the studies included in this meta-analysis may have constrained the potential adaptive effects of resistance training on sprint performance. Future studies should consider combining VBT with horizontally oriented training methods, such as sled pushes or resisted backward drags, while extending training periods to better assess the comprehensive effects on sprint performance.

Change of direction

This meta-analysis found that VBT was more effective than PBT in enhancing change-of-direction ability, with a moderate effect size (SMD = 0.45, 95% CI: [0.17, 0.73], $p < 0.01$), and low heterogeneity ($I^2 = 0\%$). Change-of-direction performance is critically dependent on efficient force application during braking and acceleration [51]. This meta-analysis shows that VBT enhances vertical explosive power (i.e., jump performance) more effectively, which increases ground reaction forces crucial for effective braking and acceleration during direction changes. Moreover, VBT's emphasis on neuromuscular control through real-time velocity feedback likely optimizes movement patterns, leading to quicker direction changes and better coordination. This is supported by previous research showing that greater neuromuscular efficiency is correlated with improved COD ability [52]. In contrast, while PBT enhances strength, its lack of velocity regulation may limit improvements in explosive power and reaction speed during change-of-direction movements [11]. Therefore, VBT demonstrates greater potential for developing change-of-direction ability.

Limitations

This meta-analysis has several limitations. First, the limited number of studies constrained the statistical power,

reducing the ability to detect moderating effects and increasing the risk of Type II errors. Second, inconsistencies in velocity regulation strategies, such as variations in velocity zones and velocity loss thresholds, introduced methodological heterogeneity, which could have influenced the results. Third, all interventions included in this meta-analysis were of short duration, with none exceeding 8 weeks. This limitation restricts the ability to assess the long-term effects of these training methods. Finally, the narrow age range of participants (16–30 years) limits the generalizability of the findings. Future studies should aim to standardize velocity regulation strategies and include a more diverse participant sample to enhance the robustness and applicability of the results.

Conclusions

VBT demonstrated small but significant advantages over PBT in improving jump performance and change-of-direction ability, while no significant differences were observed in maximal strength and sprint performance. These findings reinforce the utility of VBT in athletic performance enhancement, highlighting the need for further research to refine training protocols and explore potential moderating factors.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13102-025-01504-9>.

Supplementary Material 1: S1 File. Search Alert. S2 File. References for Excluded Studies. S3 File. Study Quality Assessment. S4 File. GRADE evidence profile. S5 File. Funnel plots. S6 File. Sensitivity Analysis.

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Authors' contributions

Conceptualization: YW, QL. Project administration: YW. Resources: YW, DD, QL. Data curation: YW, DD, XW. Software: YW, QL, XW. Supervision: QL. Writing—original draft: YW. Writing—review & editing: QL.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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