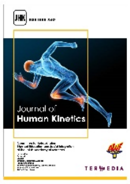

Comparison of Six-Week Velocity-Based Training versus Percentage-Based Training Programs on Lower-Body Strength and the Sticking Region in Squat Exercises

by

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This study compared the effects of velocity-based training (VBT) and percentage-based training (PBT) on lower-body strength and the sticking region in squat exercises among resistance-trained males over a six-week intervention. Twenty resistance-trained males were randomized to train in a 10% velocity loss threshold VBT group (n = 10, age = 21.96 ± 2.27 years, body height = 1.79 ± 0.04 m, body mass = 70.98 ± 6.16 kg) or a traditional PBT group (n = 10, age = 22.12 ± 2.38 years, body height = 1.78 ± 0.02 m, body mass = 74.14 ± 4.87 kg), each training twice weekly for six weeks. Changes in the squat one-repetition maximum (1RM), relative strength, the countermovement jump (CMJ), the standing long jump (SLJ), duration of the sticking region, and average velocity in the sticking region were measured using pre- and post-tests. Results indicated significant improvements in the squat 1RM, relative strength, and the CMJ for both groups, with no significant changes in sticking region velocity ($p > 0.05$). Except for squat 1RM improvements ($p < 0.01$), no other significant differences were noted between groups post-intervention ($p > 0.05$). In conclusion, both interventions significantly enhanced lower-body strength, with the VBT regimen showing greater effectiveness. Neither approach significantly altered the duration or velocity of the sticking region, though the PBT regimen yielded more favorable improvements in sticking region performance. These findings suggest that differences in muscle adaptation and strength qualities between regimens might explain the varied impacts on the sticking region. Future research could explore these aspects to further refine training strategies for improving sticking region performance across various movement phases.

***Keywords**: strength training prescription; digital resistance training; velocity loss threshold; strength adaptation; neuromuscular performance*

Introduction

Resistance training is crucial for enhancing muscle strength and athletic performance (DiNubile, 1991). The resistance training effect is determined by the training load, volume, and the type of exercise (Fry, 2004). Traditional resistance training typically determines loads based on the percentage of an individual's one-repetition maximum (1RM), referred to as percentage-based training (PBT). However, an individual's 1RM can fluctuate daily due to changes in physical condition or training status, which may lead to mismatches between the prescribed PBT training plan and the individual's actual capacity on any given day (Weakley et al., 2021). Therefore, alternative methods represented by velocity-based training (VBT) have been developed to address these limitations of PBT (Banyard et al., 2018a, 2018b; Weakley et al., 2021). By incorporating technologies such as linear position transducers (LPTs), inertial measurement units (IMUs), and cameras, VBT can adjust training loads by

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monitoring real-time metrics such as movement velocity and power output. This method enables the creation of personalized velocity profiles, the prediction of 1RM, and the monitoring of fatigue levels, offering a more robust, safe, and precise approach to training (Dorrell et al., 2019; Włodarczyk et al., 2021). Additionally, setting velocity loss thresholds, such as the commonly used 10% rule, enables achieving enhanced training effects compared to PBT with the same training volume, thereby improving training efficiency (Bachero Mena et al., 2025; Banyard et al., 2020; Dorrell et al., 2020; Held et al., 2021; Li et al., 2025; Orange et al., 2019).

Current research on VBT's impact on strength adaptation has focused on the effects of different training regimens on strength and speed (Grazioli et al., 2023; Muñoz-López et al., 2022; Ortega et al., 2020). However, research attention to the application of velocity-based training (VBT) for the enhancement of athletic performance and technical skills remains insufficient, particularly concerning overcoming critical performance limitations. A notable example of such a challenge is the 'sticking region' encountered during squats—a phase where moving the barbell upward becomes substantially more challenging (Larsen et al., 2021; van den Tillaar et al., 2014, 2024). From a performance standpoint, the sticking region acts as the proverbial weakest link in executing an exercise (Kompf and Arandjelović, 2017). It is a critical limiting factor that can significantly influence the loads an athlete is capable of managing during training. For athletes competing in sports that inherently involve weight lifting, such as weightlifting and powerlifting, overcoming the sticking region can have a direct impact on competitive outcomes (Aidar et al., 2021). In terms of safety and injury prevention, the sticking region is not only a marker of muscle fatigue, but also a pivotal moment where the mechanics of the lift can falter, leading to potential failure of the squat. In extreme scenarios, persisting through this phase without adequate control or technique can result in sports injuries, thereby highlighting the need for meticulous training practices and heightened awareness of one's physical capabilities and limits during resistance exercises (Kompf and Arandjelović, 2016; van den Tillaar, 2015).

Therefore, exploring the impact of different resistance training programs on lower-body strength and the sticking period is crucial for optimizing squat techniques, ensuring safety, and achieving peak performance. This research explored the effects of six weeks of VBT versus PBT on lower-body strength and the sticking region in squat exercises. The aim was to comprehensively evaluate the effects of these distinct training methodologies on enhancing strength and refining techniques. In light of existing evidence and the aims of this study, we hypothesized that both the VBT and PBT groups would significantly improve lower-body strength and sticking region performance following six weeks of training. Furthermore, we expected the VBT group to demonstrate greater enhancements across these measures compared to the PBT group.

Methods

Participants

The study recruited 20 resistance-trained men as participants. All participants met the following inclusion criteria: 1) at least one year of regular resistance training experience; 2) proficiency in free-weight squats; 3) a squat 1RM greater than 1.5 times their body mass; 4) no musculoskeletal injuries before the start of the training programs; 5) no illnesses or conditions affecting performance; and 6) no use of prohibited substances or drugs. The participants were randomly assigned to either an experimental group (n = 10, age = 21.96 ± 2.27 years, body height = 1.79 ± 0.04 m, body mass = 70.98 ± 6.16 kg), that followed the VBT training protocol with a 10% velocity loss threshold, or a control group (n = 10, age = 22.12 ± 2.38 years, body height = 1.78 ± 0.02 m, body mass = 74.14 ± 4.87 kg), that followed the PBT protocol. This work was conducted following the principles of the Declaration of Helsinki, and approved by the Sports Science Experimental Ethics Committee of the Beijing Sport University, Beijing, China (protocol code: 2022254H; approval date: 03 November 2022). Before the experiment, all participants were fully informed about the procedures and provided their written informed consent. The consent form confirmed the participants' voluntary participation, understanding of the study protocol, and the right to withdraw from the experiment at any time.

Experimental Procedure

Before the experiment, participants were required to provide basic information, including age, body height and mass, and to report their previous squat 1RM. A baseline squat 1RM test was conducted 72 h before the intervention. Following this, participants engaged in a six-week training program consisting of two high-intensity free-weight squat sessions per week. Three weeks into the testing, a mid-intervention squat 1RM test was conducted to update the squat weights. The post-test was conducted 72 h after the final session, using the same test protocol as the pre-test. Participants were allowed to miss their originally scheduled training time, but were required to complete the session later the same day under the supervision of the researchers. To ensure that test results were not influenced by other training or fatigue, participants were prohibited from engaging in any other lower-body training during the testing and intervention periods. Furthermore, none of the participants took any drugs, medications, or dietary supplements during the study.

Testing Protocol

Free-Weight Squat 1RM Test

After a 15-min warm-up which included 10-min light jogging and 5-min dynamic stretching, participants performed a series of squat tests at relative loads based on their estimated 1RM: 20% 1RM for three repetitions, 40% 1RM for three repetitions, 60% 1RM for three repetitions, 80% 1RM for one repetition, and 90% 1RM for one repetition. The average concentric velocity for each squat was recorded. Following these lifts, the weight in the 1RM test was progressively increased. After each successful lift, the weight was increased by 2.5–20.0 kg based on the participant's performance velocity. The weight increase continued until the participant failed a lift or the average concentric velocity of the squat fell below 0.3 m/s. At that point, the last successful load was recorded as the participant's 1RM. A 5-min rest interval was provided between attempts, with a maximum of five attempts to determine the 1RM.

Countermovement Jump Test

The initial position required participants to stand with hands on their hips and their feet shoulder-width apart or slightly narrower, maintaining a stationary position on the ground-based force plate (9281EA, KISTLER, Winterthur, Switzerland, sampling rate 1000 Hz). Upon the command to "start", participants immediately squatted and jumped upwards cohesively. Participants chose their optimal squat depth and timing for the jump and attempted to land back at the starting point. Three valid jumps were completed, each followed by a 3-min rest interval. The best performance, defined as the highest jump height, was used for subsequent analysis. Jump height was calculated based on flight time, which was derived from the vertical ground reaction force data collected by the force plate.

Standing Long Jump Test

The initial position required participants to stand with their hands naturally at their sides, knees slightly bent, and feet shoulder-width apart, toes aligned with the starting line. Upon the command to "start", participants immediately squatted, swung their arms, and jumped forward cohesively, landing in a squat position on a marked track. A staff member positioned on the side of the track recorded the position of the last foot to touch down using a camera, and the straight-line distance from the heel of this foot to the starting line was measured as the jump distance. Like the CMJ, the SLJ also involved three attempts with a 3-min rest interval in between, recording the best performance for each participant for further analysis.

Intervention Protocol

Before the interventions, a velocity test was conducted to assess the participants' training status for the day. The test included squats at 20%, 40%, and 60% of their 1RM for three repetitions each, followed by a single 80% 1RM squat. Participants in the VBT group were instructed to perform the concentric phase as quickly as possible, and the average concentric velocity of the 80% 1RM squat was recorded as the target velocity for that day. The PBT group performed the same squat tests with the same loads, but without specific velocity instructions and data recording. After the velocity test, all participants completed 20 valid squats. A valid and standardized squat required participants to achieve full hip extension (hip lockout) at the top of each repetition, and to lower the greater trochanter below the level of the knee at the bottom position. All repetitions were performed using a controlled tempo of 3/0/1/3, representing 3 s for the eccentric phase, no pause at the bottom, 1 s for the concentric phase, and a 3-s pause at the top. The concentric phase was executed with maximal intended velocity. A trained instructor positioned behind each participant ensured proper execution and controlled both technique and safety throughout all squat sessions.

For the VBT group, a 10% velocity loss threshold was applied, meaning there was no limit to the number of repetitions in each set. Still, the set would stop immediately if the average concentric velocity fell below 90% of the target velocity. After each squat, the average concentric velocity and velocity loss information was provided to the participants. The PBT group completed four sets of five squats with fixed repetitions per set. Participants from both groups were provided a 3-min rest interval between sets. After each rest interval, their rate of perceived exertion (RPE) was assessed. When the RPE was below 4, they proceeded to the next set; when it was above 4, an additional minute of rest was allowed before continuing.

Measurements

The squat data were collected using a validated strength training monitoring system (Lu et al., 2023) featuring a linear position transducer (sampling rate of 100 Hz) that recorded squat velocity and sticking region data during the intervention and testing. The sticking region of the squat was defined as the phase during the concentric movement of the squat where the difficulty of lifting the barbell increased disproportionately. This region was characterized in the velocity profile by the area between the initial maximum and the first local minimum velocity, after which the velocity increased again (Kompf and Arandjelović, 2016). This study adopted acceleration metrics to enhance the analysis and measurement of the sticking region. During the concentric phase of a lift, acceleration peaked at 0 m/s^2 at the initial maximum velocity, then decreased to assume negative values. At the first local minimum velocity, acceleration returned to 0 m/s^2 and increased positively. The sticking region was thus characterized by an acceleration transition from positive to negative, which continued to decrease before reversing back to positive. Beyond this transition, acceleration maintained a positive trajectory and progressively increased. Furthermore, as the lift's difficulty increased, the velocity changes within the sticking region were often not smooth, leading to continuous fluctuations in the acceleration data from positive to negative. Therefore, areas with a constant change in the direction of acceleration were also defined as part of the sticking region rather than merely being pinpointed to a single sticking point. This methodology enabled a straightforward identification of the sticking region, making it particularly suitable for automated detection of the sticking phase by devices. The data of the CMJ test were measured by the force plate. Data recording and analysis were conducted using the MARS software (Measurement, Analyze and Reporting Software v5.0.0.0149, KISTLER, Winterthur, Switzerland).

Statistical Analyses

Data for both the experimental and control groups were presented as mean ± standard deviation. A one-way analysis of variance (ANOVA) was used to compare differences in per-session training metrics between the VBT and PBT groups during the six-week intervention. The pre- and post-test normality data for both groups were assessed using the Shapiro-Wilk test. Differences between pre- and post-test data within each group were analyzed using paired samples *t*-tests to evaluate the effects of the respective intervention protocols. Intra-group changes from pre- to post-test were also examined using paired samples *t*-tests, with Cohen's *d* employed to quantify the magnitude of these effects. Cohen's *d* for assessing effect sizes were interpreted as small, medium, and large at 0.2, 0.5, and 0.8, respectively. Additionally, the sign of the effect size indicated the direction of the effect, signifying an increase or a decrease (Larner, 2014). Statistical significance was set at $p < 0.05$ for all analyses. The squat sticking region data were exported from the strength training monitoring system's software as CSV files and analyzed using Python 3.11 for detailed calculations. All statistical analyses were conducted in SPSS 25.0 (SPSS, Inc., Chicago, IL).

Results

As shown in Table 1, the VBT group had higher training and adjusted loads than the PBT group during both phases, likely due to higher baseline 1RM values. However, one-way ANOVA indicated no significant differences between groups in sets, repetitions, training loads, or adjusted training loads across the six-week intervention ($p > 0.05$).

There were no significant differences in the pre-test metrics between the VBT and PBT groups ($p > 0.05$). In the post-test, there was a substantial difference in the squat 1RM ($p < 0.01$) between the two groups, but no significant differences were observed in other metrics ($p > 0.05$). Figure 1 presents changes observed in various training variables from pre- to post-test across both training groups, and Table 2 presents a detailed comparison of the training variables.

The body mass of the VBT group was 74.14 ± 4.87 kg at pre-test and 74.95 ± 3.91 kg at post-test, while for the PBT group, it was 70.98 ± 6.16 kg and 71.19 ± 5.09 kg, respectively. No significant changes in body mass were observed within or between groups over the intervention period ($p < 0.05$). For lower-body strength, except for the standing long jump, both the VBT and PBT groups showed significant improvements in the squat 1RM, relative strength, and the CMJ after the intervention. The VBT group had a large effect on the squat 1RM (Cohen's d = 0.91) and relative strength (Cohen's d = 1.31), while the PBT group showed a large effect on the squat 1RM (Cohen's d = 0.88), but a moderate impact on relative strength (Cohen's d = 0.77). Considering the CMJ, the VBT group improved by 6.68%, with a moderate effect size (Cohen's d = 0.43), while the PBT group saw a smaller increase of 3.88% with a similar effect size. This indicates that both groups enhanced their explosive jumping ability, but the VBT group presented a slightly more pronounced improvement. For the SLJ, both groups experienced modest gains: the VBT group improved by 1.26% and the PBT group by 0.89%, both achieving small effect sizes.

The data of the sticking regions that occurred at maximal or near-maximal weights (90–100% 1RM) were selected for analysis. However, not all participants exhibited the characteristic sticking region during the maximal load squat. In the pre- and post-test squats, one participant (n = 1) did not display a sticking region at all, two participants (n = 2) overcame the sticking region in the post-test after the intervention, and four participants (n = 4) did not show a sticking region in the pre-test, but displayed it in the post-test. Due to this variability, the analysis was limited to those participants who exhibited a sticking region during both the pre- and post-test in 90–100%1RM squats (VBT: n = 7, PBT: n = 6). After the intervention, there were no significant differences between the VBT and PBT groups in the sticking region time ($p > 0.05$) and sticking region velocity ($p > 0.05$). However, the two groups showed different responses in the sticking region. The intervention had minimal effect on the duration of the sticking region in the VBT group (Cohen's d = −0.09), while it significantly reduced the duration in the PBT group (Cohen's d = −0.88). Regarding the sticking region velocity, outcomes also differed between the groups. The intervention had little impact on the sticking region velocity of the PBT group (Cohen's d = 0.04), while it moderately decreased the velocity in the VBT group (Cohen's d = −0.67).

Table 1. Per-session training metrics for VBT and PBT groups during the six-week intervention.

Training Metrics	VBT (Weeks 1–3)	PBT (Weeks 1–3)	VBT (Weeks 4–6)	PBT (Weeks 4–6)
Sets	3.91 ± 0.99	4.00	3.94 ± 0.76	4.00
Reps	5.47 ± 1.56	5.00	5.27 ± 1.04	5.00
Training Load (kg)	2398.40 ± 292.01	2136.00 ± 229.22	2496.00 ± 247.35	2208.00 ± 210.35
Adjusted Training Load (kg)	2396.00 ± 296.62	2130.00 ± 228.25	2510.00 ± 242.69	2204.00 ± 210.10

Sets: number of sets performed per training session; Reps: number of repetitions completed per set; Training Load: calculated as the product of the lifted weight and the total number of repetitions performed per session; Adjusted Training Load: accounts for individual training load modifications (within ± 2 kg) due to equipment limitations or participant-specific adjustments

Table 2. Comparison of the training variables between the VBT and PBT groups.

Test	Group	Pre-test	Post-test	Improvement	Cohen's *d*
Squat 1RM (kg)	VBT	149.90 ± 19.24	164.70 ± 13.29	10.64%	0.91
	PBT	133.50 ± 15.10	145.70 ± 12.58	9.59%	0.88
Squat Relative Strength	VBT	1.99 ± 0.19	2.20 ± 0.13	10.64%	1.31
	PBT	1.88 ± 0.24	2.05 ± 0.20	10.59%	0.77
Countermovement Jump (cm)	VBT	59.82 ± 9.33	63.53 ± 8.10	6.68%	0.43
	PBT	60.45 ±5.79	62.76 ± 4.99	3.88%	0.43
Standing Long Jump (m)	VBT	2.81 ± 0.19	2.84 ± 0.16	1.26%	0.17
	PBT	2.74 ± 0.14	2.77 ± 0.14	0.89%	0.21
Sticking Region Time (s)	VBT	0.36 ± 0.35	0.33 ± 0.34	–7.88%	–0.09
	PBT	0.46 ± 0.21	0.24 ± 0.29	–48.51%	–0.88
Sticking Region Velocity (m/s)	VBT	0.19 ± 0.08	0.14 ± 0.07	–21.28%	–0.67
	PBT	0.15 ± 0.05	0.15 ± 0.09	2.98%	0.04

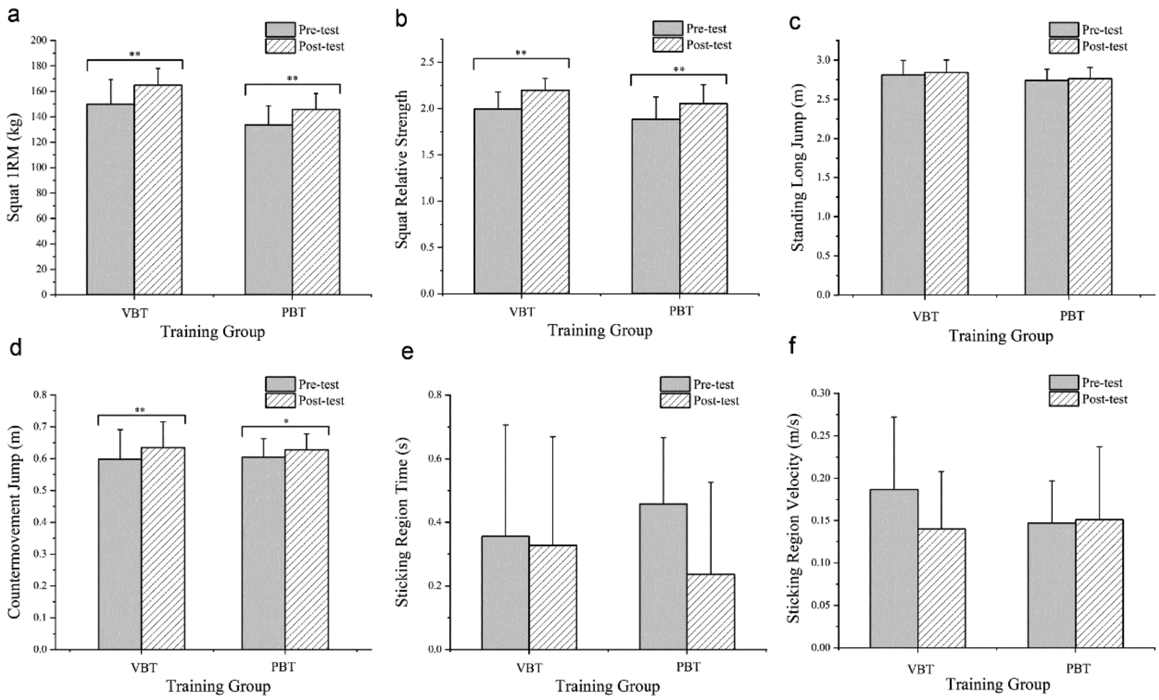

Figure 1. Comparison of the training variables (mean ± SD) between pre- and post-test.
*(a): squat one-repetition maximum, (b): squat relative strength, (c): standing long jump, (d): countermovement jump, (e): sticking region time, (f): sticking region velocity, * significant differences between tests at p ≤ 0.05 level, ** significant differences between tests at a p ≤ 0.01 level*

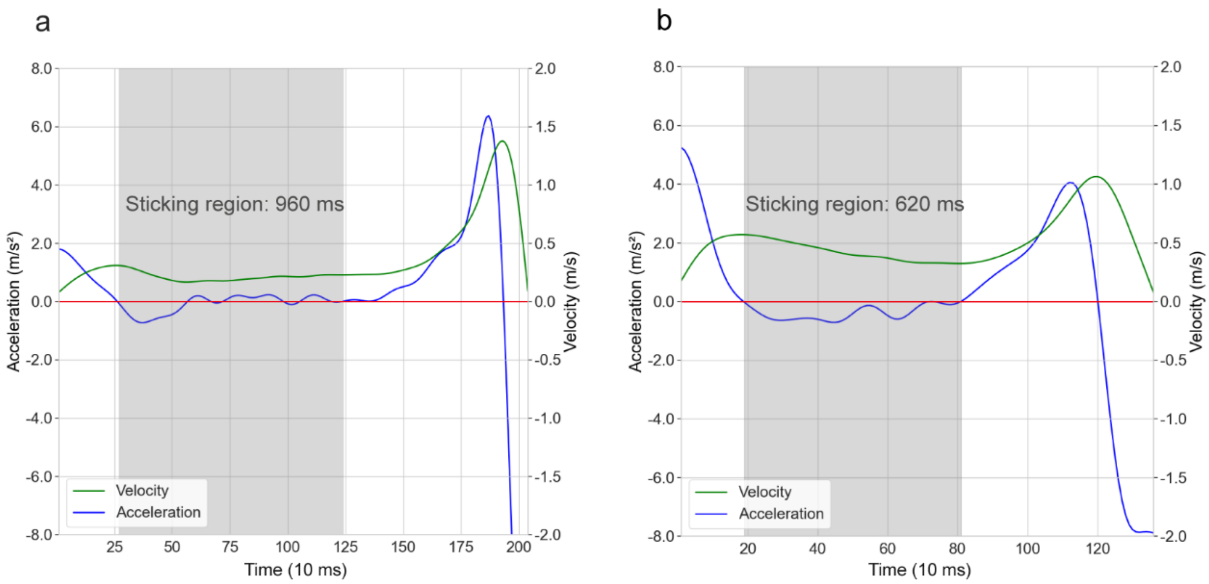

Figure 2. Sticking region changes between pre- and post-test: (a): sticking region during the pre-test, (b): sticking region during the post-test.

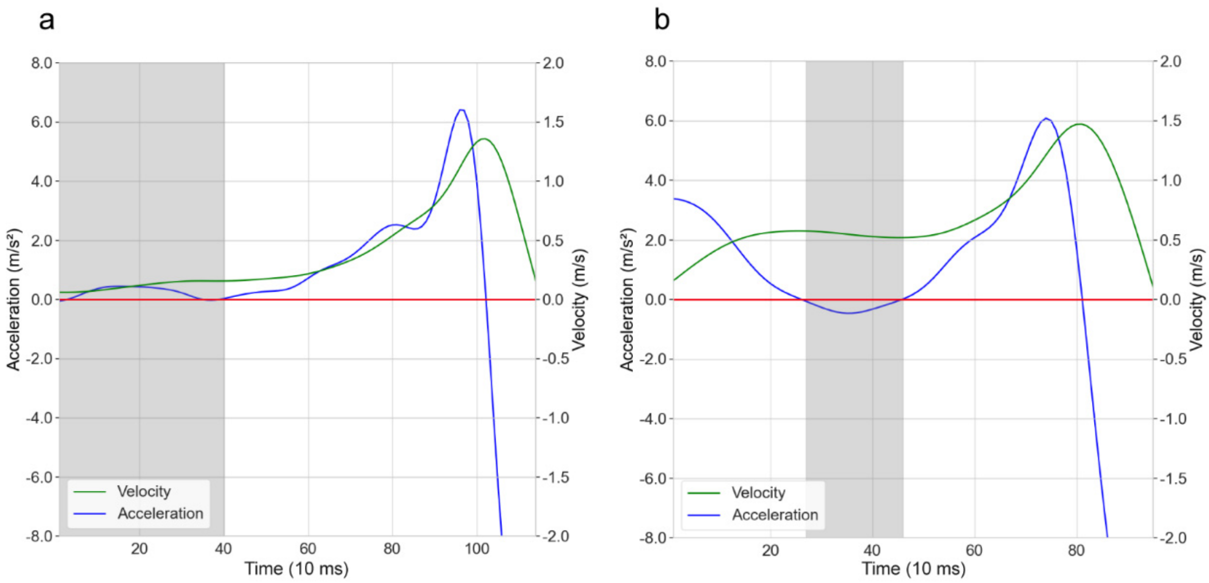

Figure 3. Sticking region at different phases of the squat: (a): the sticking region appears in the initial phase of the squat during the commencement of the ascent, (b): the sticking region appears in the middle phase of the squat during the upward movement.

Discussion

The results of this study confirmed that, compared to PBT, VBT led to more substantial improvements in lower-body strength in participants (Dorrell et al., 2020). Regarding the sticking region of the squat, the PBT intervention reduced the duration of the sticking region, while the VBT protocol decreased the average velocity during the sticking region. These outcomes are partly in line with our hypothesis. Both groups improved lower-body strength, with VBT producing greater gains in 1RM and jump performance. However, neither protocol significantly improved sticking region measures, suggesting that longer training duration or alternative loading strategies may be needed to elicit measurable changes. Given the factors influencing the sticking region, this finding warrants further investigation.

Lower-Body Strength Performance

The intra-group analysis indicated that the VBT and PBT groups experienced significant improvements in the squat 1RM and relative strength following the intervention. However, between-group comparisons revealed a notable difference in the squat 1RM between the VBT and PBT groups, while no significant difference was observed in relative strength. This finding aligns with previous research (Banyard et al., 2020; Dorrell et al., 2020). To evaluate the changes in lower-body strength more accurately, this study incorporated relative strength metrics that considered changes in body mass alongside strength gains.

This approach was relevant as the body mass changes observed during the six-week intervention differed significantly between the groups, with the VBT group showing a 1.10% increase and the PBT group only a 0.30% increase. These disparities highlight the necessity of integrating body mass variations when evaluating strength gains. Monitoring both absolute and relative strength is recommended for interventions extending beyond six weeks. Employing relative strength metrics offers a deeper insight into an individual's strength capacity relative to their body mass, providing a more precise evaluation of training effectiveness. For the jump test, the VBT group improved by 6.68% with a moderate effect size (Cohen's d = 0.43), compared to the PBT group's smaller 3.88% improvement in the CMJ. In the SLJ, gains were modest across both groups, with the VBT group improving by 1.26% and the PBT by 0.89%, showing small effect sizes. These results suggest that VBT slightly surpasses PBT in enhancing vertical and horizontal explosive strength, highlighting its potential benefits for improving overall athletic performance.

Sticking Region Performance

After the intervention, the intra-group comparison showed no significant changes in the sticking region duration or average velocity indicators in either the VBT or PBT groups. There were no significant differences between the groups. The study found that the PBT protocol reduced the sticking region duration during maximal load squats by 48.51%, compared to the VBT protocol. In contrast, the VBT group, in which training velocity was emphasized, showed a 7.88% decrease in the average velocity during the sticking region in maximal load squats rather than an improvement compared to the PBT group. This indirectly suggests that participants in the VBT group encountered greater resistance when performing maximal load squats than those in the PBT group after the intervention. Although previous studies had shown that improving both velocity and strength qualities could effectively reduce the sticking region time (Cronin et al., 2001; Gamble, 2006), particularly with moderate-to-low load velocity training (50%–60% 1RM), typically using short rest intervals (45–60 s) and maximizing acceleration, this type of training was commonly used in daily training of powerlifters and weightlifters (Swinton et al., 2009; Young, 1993). However, improving the sticking region by enhancing velocity and strength involves overcoming the same load, effectively altering the participant's relative load. In this study, the 1RM changed to varying degrees, but the relative load during testing did not change. Notably, one participant’s 1RM did not change following the intervention, yet their sticking region duration was significantly reduced, and their average velocity during the sticking region improved (Figure 2). This phenomenon further supported the findings from previous research.

However, factors influencing the sticking region vary among individuals (Dusan et al., 2024; Kompf and Arandjelović, 2016, 2017). Based on existing research, we hypothesize that the following three factors may explain this phenomenon.

First, the imbalanced muscle adaptation to training may play a role here. Research suggests that the primary cause of the sticking region is the presence of a "weakest link" in the muscle or functional muscle groups during resistance training (Arandjelović, 2011; Kompf and Arandjelović, 2017). Compared to the PBT group, the VBT group experienced a greater increase in lower-body maximal strength, which might have led to more imbalanced muscle adaptations within the shorter intervention period. This imbalance in strength adaptation could cause the sticking region to appear at different stages of the squat (Figure 3). This may explain why some participants did not experience a sticking region in the pre-test but did in the post-test at maximal squat loads.

Secondly, different strength qualities are developed by different training protocols (McGuigan et al., 2012). Some studies have shown that isometric training can effectively improve the sticking region (Graves et al., 1989; Kitai and Sale, 1989; O'Shea and O'Shea, 1989). In squat training, the sticking region tends to occur in the last few repetitions of each set or during the fatigue accumulation phase of training, where muscles engage in isometric contractions to resist the load (van den Tillaar, 2015). In this study, compared to the fixed sets and repetitions in the PBT group, the 10% velocity loss threshold in the VBT group greatly reduced the likelihood of a sticking region to occur, thus minimizing the potential for isometric muscle contractions during squat training.

Thirdly, high individual variability in the sticking region should be considered (Kompf and Arandjelović, 2016). Different participants exhibit different force-velocity relationships (Thompson et al., 2023), and the impact of strength improvements on squat velocity varies from person to person. Moreover, the sample size of participants (n = 13) who experienced the sticking region both before and after the intervention was relatively small in this study. Future research should expand the sample size and focus on participants with characteristic sticking region traits to better understand this phenomenon.

In conclusion, neither the VBT nor the PBT protocol significantly improved the sticking region during maximal load squats in this study. However, compared to the VBT group, the PBT group showed better adaptation in terms of both the duration and the sticking region velocity. Future studies should consider extending the intervention period and increasing the sample size. Additionally, future research should quantify the occurrence of the sticking region during training to further explore the effects of different training protocols on it. Moreover, considering the simplicity of collecting velocity compared to force and power data, future developments and applications of strength training monitoring and assessment tools could more widely incorporate velocity data and its derived metrics. For instance, using velocity loss to monitor training quality and utilizing acceleration metrics to assess the sticking region could help optimize movement quality and prevent sports injuries.

Limitations

A limitation of this study is the small sample size included in the sticking region analysis (VBT: n = 7; PBT: n = 6). Due to individual variability in motor patterns, not all participants exhibited a clearly defined sticking region under maximal load conditions. This reduced the statistical power to detect meaningful between-group differences. Post hoc power analyses using G*Power revealed low statistical power for the VBT group in both sticking region time (Cohen's $d = -0.09$, power = 0.05) and sticking region velocity (Cohen's $d = -0.67$, power = 0.20), as well as for the PBT group in sticking region velocity (Cohen's $d = 0.04$, power = 0.05). Only the PBT group demonstrated a modest power value in the sticking region time (Cohen's $d = -0.88$, power = 0.30). Although the power values were below the conventional threshold of 0.80, these results provide preliminary insights into group-specific adaptations. Future research would benefit from larger samples and individualized methods for identifying and analyzing the sticking region to strengthen the reliability and generalizability of the findings.

Fatigue in this study was assessed exclusively through CMJ height, which may not fully capture the complexity of neuromuscular fatigue. The inclusion of additional biomechanical variables, such as ground contact time, peak power, and the reactive strength index, could provide a more comprehensive assessment of the impact of fatigue on explosive performance. Moreover, physiological indicators such as tensiomyography and biochemical markers were not considered, which may have limited insights into underlying intramuscular fatigue mechanisms and recovery processes. Future research should take into account integrating these measures, along with larger sample sizes and broader assessment protocols, to enhance the interpretability and generalizability of findings.

Conclusions

This study compared the effects of six-week VBT and PBT on lower-body strength and performance in the sticking region during squat exercises among resistance-trained males. The findings revealed that both VBT and PBT significantly enhanced lower-body strength, with VBT showing a more pronounced effect. Although neither training method significantly changed the duration or velocity of the sticking region during squats, the PBT program resulted in more favorable improvements in the sticking region. These differences might be attributed to factors such as uneven muscle adaptation, the distinct strength qualities developed by each training regimen, and the highly individualized nature of the sticking region. Future research should delve deeper into these aspects to refine training strategies that enhance performance in the sticking region across various movement phases.

Practical Implications

Selecting the appropriate resistance training protocol is essential for optimizing specific training goals in squat performance, particularly for enhancing strength and improving movement mechanics. VBT and PBT both effectively increase lower-body strength. VBT excels in boosting power, while PBT provides better improvements in the performance of the sticking region. Personalized training adjustments, tailored to an athlete's unique strength and velocity profiles and accompanied by monitoring the body mass changes, optimize training outcomes. Integrating velocity and acceleration data into training monitoring tools provides richer performance insights and enhances injury prevention strategies.

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