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Original Research

Effect of Velocity-Based Training on Vertical Jump Performance by Beach Volleyball Players

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Abstract

International Journal of Exercise Science 18(3): 1061-1071, 2025. https://doi.org/10.70252/DFMZ2015 The aim of this study was to examine variations in countermovement jump (CMJ) performance after two velocity-based training (VBT) protocols in the half-squat exercise. Sixteen male beach volleyball athletes performed CMJ tests before and after three experimental sessions on the half-squat exercise. The two VBT protocols were performed in three sets, at a mean propulsive velocity (~ 0.49 m•s^{-1}) associated with relative intensity (~ 85% 1RM), with three minutes interset recovery. In the VL0-10 session, the participants stopped their sets upon reaching a velocity loss (VL) threshold of 10%. In the VL10-20 session, participants stopped their sets upon reaching a VL between 10% and 20%. The VL0-10 session showed progressive increases in CMJ height ($P < 0.05$). Comparisons between different times-points in each session showed that VL0-10 was greater than VL10-20 (mean difference = 3.7 cm; $P < 0.001$) after four minutes. Additionally, VL0-10 was greater than both VL10-20 ($P = 0.005$) and the control ($P = 0.006$) after six minutes. Thus, CMJ height performance appears to be optimised with VBT protocol involving small VL. For beach volleyball athletes, a half-squat protocol with 0-10% VL improves subsequent acute performance in CMJ height.

Keywords: Velocity loss, post-activation potentiation, countermovement jump

Introduction

Beach volleyball is an intermittent sport characterised by repeated jumps to attack and block. In a typical beach volleyball match, players usually execute an average 29.9 jumps per set.[1] Therefore, the performance in vertical jump during matches is fundamental in this sport.[2] As a result, various training strategies have been proposed to improve vertical jump performance by correctly manipulating several variables, such as training load, training volume, set configuration, and rest period.[3]

In contrast training, all high-load strength exercises are performed at the beginning of the session, followed by lighter load power exercises at the end.[4] This sequencing of biomechanically similar exercises, in which the protocol with heavy loads is considered the conditioning activity (CA), may yield post-activation performance enhancement (PAPE) in subsequent high-velocity exercises.[5] Moreover, sports such as volleyball involve athletes who are already highly trained in jumping, suggesting that PAPE effects are a viable method for these athletes.[3]

However, designing contrast pairs to obtain PAPE on vertical jump height involves several prescription variables in the CA.[3] Generally, traditional resistance training is performed to volitional failure, during which movement velocity decreases throughout repetitions.[6,7] Thus, velocity-based training (VBT) has been suggested as an objective method that accurately monitor movement velocity during resistance exercise.[8] One important practical application of VBT is the introduction of velocity loss (VL), a parameter that determines the threshold of fatigue based on the relative reduction of movement velocity throughout repetitions.[8] Protocols with lower VL limits also show fewer repetitions compared to those with greater limits, allowing VL to be used to control training volume.[8] Additionally, velocity loss was strongly correlated with peak post-exercise lactate concentration, suggesting greater metabolic stress in protocols with higher magnitudes of speed loss.[9] Velocity-based training is essential for optimizing athletic performance, as it allows for precise load adjustments based on real-time movement speed, enhancing strength, power, and skeletal muscle hypertrophy.[10] The VBT prescription involves setting a target velocity related to a percentage of one-repetition maximum (1RM), such as the mean propulsive velocity (MPV) associated with 80% of 1RM (MPV at 80% of 1RM) and stopping the sets when the predetermined percentage of VL is reached.

In this scenario, the VL strategy during a CA may help to determine the degree of fatigue and provide sufficient stimulus to promote PAPE. This can be an effective strategy to optimize the movement economy, reduce fatigue, and induce acute improvements in performance, such as the ability to produce force quickly and efficiently in vertical jumps.[9,11] Few studies have investigated the acute effect of VBT in squat exercises on countermovement jump (CMJ) height revealing that high loads (≥80%-of 1RM) and 20% VL reduced subsequent CMJ height in resistance trained subjects.[11,12] Therefore, more detailed knowledge of the percentage of VL in the CA will enable strength and conditioning coaches to establish appropriate training strategies for beach volleyball athletes to promote PAPE.

Thus, this study examined two VL protocols applied in the half-squat exercise and the subsequent variation in CMJ. It was hypothesized that positive effects on CMJ performance would be observed for both experimental conditions (up to 10% and between 10 and 20% VL) between four and six minutes after the CA. This hypothesis was based on the assumption that this time interval would be a suitable window to elicit PAPE.[13,14] Furthermore, a greater improvement in CMJ performance is expected for the protocol with lower VL due to its lower metabolic demand.

Methods

A repeated, randomised design was used to examine the variations in CMJ performance after two VBT protocols and one control session in half-squat exercise. Participants visited the laboratory on six occasions, including one for familiarisation with the load-velocity relationship, a real session for load-velocity relationship determination, one for familiarisation with CMJ and three for the experimental sessions. Countermovement jump tests were performed before and after the experimental sessions. The heights attained during the CMJ tests were used as CMJ performance indicators.[15,16] All sessions were completed within nine days in a randomised manner (www.randomization.com), allowing for 72 hours of rest between sessions (Figure 1) at the laboratory of the university. The sessions were performed at the same time of day. The visits were conducted in a controlled environment, at temperatures of 20-22ºC and relative humidity of 60%.

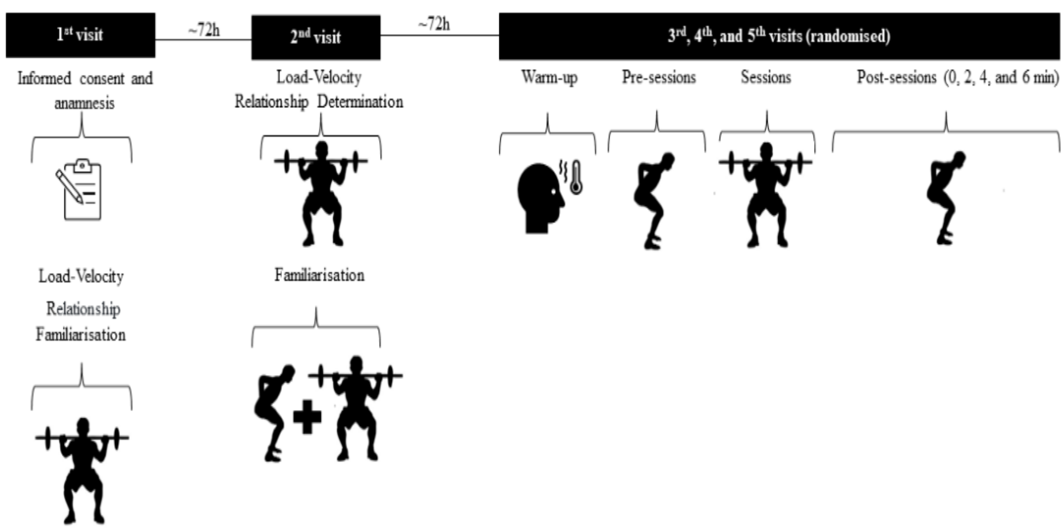

Figure 1. Study Overview.

Participants

Sixteen male beach volleyball athletes (age = 23.2 ± 4.2 years; height = 1.80 ± 0.1 m; body mass = 76.1 ± 10.6 kg; back squat:body weight ratio = 1.5 ± 0.2) volunteered to participate in this study. The number of participants was determined based on samples from previous studies.[5,17] Participants were competing at the state or national level, but during the interventions, the participants were not excluded from competitions; they continued their usual training on the sand and gym. All subjects had a minimum of three years of experience in beach volleyball and trained at least four days a week on their routine. Additionally, all athletes had at least two years of resistance training experience. During the intervention, participants typically performed strength training sessions an average of three times per week, sometimes on the same day as their beach volleyball training. They engaged exclusively in traditional strength exercises (squats, deadlifts, hip thrusts, bench presses, and rows). Participants were not following any specific strength training program and were performing plyometric exercises. In addition, participants were instructed not to perform any resistance training sessions during data collection. None of the athletes had physical limitations, health problems, or injuries during the procedures, nor were any taking medications, drugs or supplements that might alter their physical performance. Each participant signed a declaration of free, informed consent, and the study was approved by the local university research ethics committee (protocol number# 6.262.579) in accordance with the Declaration of Helsinki. This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.

Protocol

Load-Velocity Relationship Familiarisation: to begin with, the evaluator provided instructions and demonstrated the load-velocity relationship procedure. The half-squat exercise was performed according to the recommendations by Pérez-Castilla et al[18] An elastic tape was placed to limit knee flexion to 90º during the eccentric phase of the movement. A previous study (13) showed high test-retest intra-class correlation coefficient values for knee angle variation in a CMJ test (ICC = 0.97). Participants were instructed to perform both movement phases with the intention of attaining highest possible velocity.[18] Subsequently, familarisation with the load-velocity relationship in the half-squat was conducted. During familiarisation, individual load-velocity relationships in the half-squat exercise were ascertained through a progressive loading test. First, participants warmed up by performing six repetitions with a 10-kg load. The starting load was set at 20 kg for all participants and progressively increased in 15-kg increments until mean propulsive velocity (MPV) of < 0.60 m•s^{-1} was attained. Two attempts were performed with lighter and medium loads, with a 1-min recovery period between loads. Rest interval between sets were set to 3-min for the lighter loads (MPV ≥ 1.00 m•s^{-1}) and 5-min for the medium loads (MPV < 1.00 m•s^{-1}). Only one repetition was performed with heavy loads (MPV < 0.60 m•s^{-1}) with 5-min of recovery between loads. The average number of incremental loads tested during the half-squat exercise was 6.9 ± 0.7. This procedure conducted by Pérez-Castilla et al[20] served as the basis for the subsequent visit to determine individualised load-velocity rrelationships.[18] The limitations associated with that method (time cost and greater fatigue) were reduced by using a two-point method, which has been shown to be reliable and safe.[21]

Determining load-velocity relationship.

The individual L-V relationship in the half-squat exercise was determined using the two-point method.[18] First, participants warmed up by performing six repetitions with a 20-kg load. Participants then completed two attempts with medium loads (MPV < 1.00 m•s^{-1} ≥ 0.60 m•s^{-1}) and one with heavy loads (MPV < 0.60 m•s^{-1}) [16]. Rest periods between attempts with medium loads were set to 5-min. The choice of medium and heavy loads was informed by the strategies of the familiarisation visit. The following strategies were applied to minimise measurement errors: a) all participants had good technique and tolerance of discomfort in the half-squat exercise; b) a simple linear regression model was used; c) the accuracy of the L-V relationship was estimated using the medium and heaviest loads; d) the warm-up was designed to ensure that participants could attain their fullest potential with the two loads; e) the minimum velocity threshold corresponding to the heaviest load was < 0.6 m•s⁻¹; and f).[21,22] The device used (Vitruve®, Madrid, Spain) is valid and reliable for providing MPV outputs.[23]

Familiarisation.

First, a brief warm-up was performed on a model adapted from Külkamp et al[24] In this warm-up, participants performed two sets of 10 jump-rope movements and 10 submaximal CMJs. This warm-up strategy was selected for its similarity to the study outcome, as suggested by Blazevich and Babault.[25] Participants then underwent procedures to familiarise themselves with the CMJ test. The evaluator gave instructions and demonstrated the CMJ. The following procedures were adopted: a) participants performed the CMJs with their hands on their hips, starting from a static standing position and keeping their legs straight during the flight phase of the jump;[26] b) participants lowered to ~ 90º during knee flexion;[19] and c) participants were instructed to jump as high as possible. Familiarisation with the experimental sessions was conducted similarly to the real sessions. However, each participant was allowed to perform each experimental protocol twice.

Before and after CMJ assessments, participants underwent three experimental sessions of the half-squat exercise: control and two VBT protocols. In the control session, participants completed only the warm-up, consisting of two sets of 10 jump-rope movements and 10 submaximal CMJs. The two VBT protocols involved three sets of the half-squat exercise at a relative intensity (~ 85% of 1RM) with three minutes of interset recovery. This protocol was chosen for its PAPE effect on CMJ height performance.[13] Relative loads were determined based on individual load-velocity relationships obtained from each participant's progressive loading half-squat test. Individual loads were thus adjusted at each training session to ensure the corresponding MPV (± 0.03 m•s⁻¹) matched the prescribed 85% of 1RM. This load adjustment was performed with a maximum of 3 repetitions and a 1-minute interval between repetitions, conducted 10 minutes before the warm-up period. All repetitions by all participants during in all sessions were recorded using a linear position transducer (LTP) (Vitruve®, Madrid, Spain) which is valid and reliable for evaluating movement velocity in non-plyometric exercises.[23]

The two VBT protocols differed in the level of fatigue induced during the exercise sets, objectively quantified by the magnitude of VL achieved in each set and consequently, in the number of repetitions performed per set. In the VL0-10 session, participants stopped their sets upon reaching the corresponding VL threshold (i.e., up to 10% VL). Conversely, in the VL10-20 session, participants stopped their sets upon reaching the corresponding VL threshold (i.e., between 10 and 20% VL). This choice was based on a previous study demonstrating similar gains in jumping performance with moderate and low VL (20% vs. 5%), despite the VL20 group achieving only 32.6% of the repetitions performed by the VL5 group.[27] Moreover, participants received real-time velocity feedback and were encouraged to perform each repetition at the maximal intended velocity during each session.

Countermovement jump assessment: participants performed three jumps at 15-second intervals before each of the three experimental sessions.[28] Following the sessions, a CMJ was performed at four and six minutes (i.e., Post-0, Post-2, Post-4, and Post-6, respectively). For measurement purposes after the sessions, participants completed only one CMJ. The jump procedures were similar to those used during familiarisation with CMJ. Jump height served as the performance indicator (3,15). All CMJs were assessed using an Ergonauta encoder (Ergonauta®, Florianópolis, Brazil), which provides 400 pulses/revolution, 1 mm/pulse resolution and variable sampling frequency, where pulses are time-stamped at high resolution (approximately every 10 ms). The encoder has demonstrated reliability and validity in assessing CMJ height performance.[29]

Statistical Analysis

First, at baseline, application of the Shapiro-Wilk test returned a normal data distribution for CMJ height ($p > 0.05$). Thus, a two-way repeated-measures analysis of variance (ANOVA) was used with Bonferroni post-hoc correction to investigate the effect of the sessions (VL0-10, VL10-20 and control) and times (i.e., Pre-sessions, Post-0, Post-2, Post-4 and Post-6) on height. The Mauchly test was used to examine the sphericity of the data. If sphericity was violated, the Greenhouse-Geiser factor was applied. Data were reported as means and standard deviations (M ± SD). All statistical analyses were performed using the Social Sciences Statistical Package software (IBM SPSS version 22.0, Chicago, IL, USA) at $P < 0.05$.

Results

Descriptive data for the VBP protocols used in the half-squat exercise with different VL (0-10% and 10-20%) are given in Table 1 below.

Table 1. Characteristics of performance between sessions (reported as means and standard deviation [M±SD]).

Sessions x sets	Reps	MPV All reps ($m.s^{-1}$)	Fastest MPV ($m.s^{-1}$)	Slowest MPV ($m.s^{-1}$)	Mean VL (%)
VL0-10					
1st set	2.0 ± 0.0	0.47 ± 0.05	0.48 ± 0.05	0.45 ± 0.04	5.6 ± 2.4
2nd set	2.0 ± 0.0	0.45 ± 0.05	0.47 ± 0.05	0.44 ± 0.05	5.8 ± 3.0
3rd set	2.0 ± 0.0	0.46 ± 0.04	0.48 ± 0.04	0.45 ± 0.04	3.5 ± 4.4
VL10-20					
1st set	3.4 ± 1.0	0.45 ± 0.04	0.49 ± 0.04	0.41 ± 0.03	15.3 ± 2.9
2nd set	2.2 ± 0.4	0.44 ± 0.03	0.47 ± 0.04	0.40 ± 0.03	13.9 ± 3.2
3rd set	2.3 ± 0.4	0.42 ± 0.03	0.45 ± 0.03	0.39 ± 0.03	13.0 ± 2.7

Legend: Reps = repetitions; MPV = mean propulsive velocity; VL = velocity loss

The results showed main effects for sessions ($F_{(2, 32)} = 5.908$; $P = 0.007$; $\beta = 0.840$) and times ($F_{(1.480, 23.684)} = 13.466$; $P < 0.001$; $\beta = 9.810$). An interaction between sessions and times was also observed ($F_{(2.782, 44.507)} = 11.540$; $P < 0.001$; $\beta = 0.998$). The effects of time in each session are shown in Figure 2. In turn, comparisons between the different times of each session are shown in Figure 3.

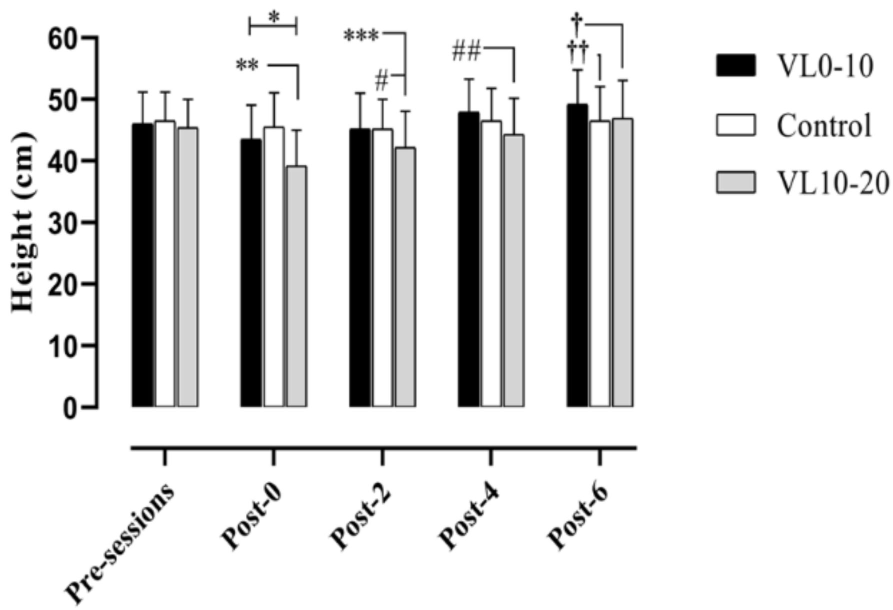

Figure 2. Comparison of changes in CMJ height between experimental sessions. Legend- Post-0: *Control > VL10-20 (mean difference = 6.2 cm; $P < 0.001$), and VL10-20 (2,0 cm; $P = 0.009$), respectively; **VL0-10 > VBT10-20 (mean difference = 4.3 cm; $P < 0.001$); Post-2: #Control > VL10-20 (mean difference = 3.0 cm; $P = 0.046$); *** VL0-10 > VL10-20 (mean difference = 2.9 cm; $P = 0.001$); Post-4: VL0-10 > VBT10-20 (mean difference = 3.6 cm; $P < 0.001$); Post-6:† VL0-10 > VL10-20 (mean difference = 2.3 cm; $P = 0.011$); ††VBT0-10 > Control (mean difference = 2.7 cm; $P = 0.013$).

Discussion

The purpose of this study was to examine two VL protocols applied in the half-squat exercise and the subsequent variation in CMJ. The main finding of this study was that the protocol with 0-10% of VL improved CMJ height performance in the beach volleyball athletes. While both VL conditions showed a reduction in performance immediately after the half-squat, VL0-10 returned to baseline values two minutes after the session and showed improved performance at the post-4 and post-6 time-points. In contrast, VL10-20 showed a significant reduction in performance until post-6, without PAPE effects. Furthermore, the VL0-10 condition showed significant fewer repetitions performance in the half-squat compared to VL10-20.

Similar findings were observed by Yuan et al[30] who compared four VL conditions in the back squat and their post-exercise effects on CMJ performance. In their study, 5% of VL improved CMJ performance, whereas 10%, 15% and 20% VL showed no significant changes. Based on these results, the VL threshold capable of inducing PAPE effects should not exceed 10% for CMJ performance. In contrast, Seitz and Haff[13] demonstrated in their meta-analysis that near repetition maximum efforts produce greater PAPE effects than sub-maximal efforts, favouring CAs with higher VL. The main reason for this divergent finding is attributed to the individual response during CA application. Hamada et al[31] suggests that PAPE effects occur with muscle activation and phosphorylation of the light chain regulatory myosin, without excessive fatigue. In the context of fitness-fatigue paradigm, using VL can effectively individualize the best protocol for each subject. Thus, higher VL thresholds increase acute metabolic responses and perceived exertion rates, compromising neuromuscular performance, whereas lower VL threshold produce the opposite effect.[8,32] Therefore, prescribing protocols based on VL thresholds should guide the control of metabolic and neuromuscular responses during a CA implementation.

In a VBT, there is an inverse relationship between VL and repetitions performance in each set, which significantly impacts training volume. In a longitudinal study, Pareja-Blanco et al[11] revealed greater repetitions performed at 40% VL compared to 20%. Consequently, training at higher VL showed greater skeletal muscle hypertrophy adaptations, while lower VL showed greater benefits for CMJ performance. Considering that protocols aimed at inducing PAPE usually involve higher-loads (≥ 85% of 1RM), it is common to use fewer repetitions. However, using a relative load based on 1RM and fixed repetitions for all subjects may not effectively individualize the CA. Thus, to accurately determine the intensity of CA, it is essential to consider not only the relative load but also the relative VL value in each set. Moreover, the use of three sets used in this study aligns with previous recommendations for inducing PAPE in athletes, emphasizing the importance of applying multiple sets of brief, high-load stimuli, in CA protocols.[13,33,34] Therefore, from a practical perspective, strength training sessions should begin with sets that serve as the CA, ensuring that VL does not exceed 10%. Throughout the session, exercises should remain within a 20% VL margin if the goal is to develop maximal strength and high-velocity movements.

Finally, both protocols decreased performance immediately after CA due to increased fatigue, which supressed the potentiation effects, similar to observed in previous studies.[5,6,17] During recovery, the time-course differed between conditions, with the VL0-10 session showing similar performance results to baseline at post-2-min, while VL10-20 fully recovered only by post-6. Moreover, at the post-6 time-point, VL0-10 showed PAPE, consistent with findings by Gouvea et al[35], who reported an optimal window between eight to 12-min after CA. Other studies, such as those by Seitz and Haff[13], suggests that PAPE effects are observed between five to seven minutes post-session, while Wilson et al[14] indicated performance benefits for athletes three to seven minutes after CA. Thus, VL0-10 CA was able to induce PAPE at a time-point observed in previous studies, with detrimental effects due to fatigue seen immediately after, while a prolonged residual effect was observed with higher VL.

One limitation of this study concerns the use of a combination of half-squat and CMJ executed with a 4-min post-session interval, which may have induced PAPE in CMJ at the 6-min post-session time-point. However, this limitation is common in studies investigating the optimal time interval to elicit PAPE during CMJ.[13,14] Furthermore, our findings demonstrated progressive increases in CMJ height after the VL0-10 session, which partly mitigate this issue. Using only jump height as an outcome in the CMJ can be considered a limitation, as other variables can be analyzed during a vertical jump test and contribute to a better understanding of PAPE effects. However, height is a highly relevant measure that can be easily obtained. This finding can support its application in strength training sessions for beach volleyball athletes by strength and conditioning coaches due to its high practical applicability. Another limitation is related to the control of knee angle variation during exercise and jumping sessions, although the strategy employed resulted in a high intra-class correlation coefficient.[19] Lastly, a longer follow-up period would be beneficial to explore the potential long-term effects of the experimental sessions on CMJ performance.

Thus, CMJ height performance appears to be optimised in the VBT protocol with a lower VL threshold. Coaches should consider CA protocols in the half-squat that do not exceed 10% of VL when aiming to promote PAPE in CMJ. Conversely, the VBT protocol with higher VL appears to be counterproductive for inducing improved performance in these athletes. For beach volleyball athletes, application of a warm-up with multiple sets of high-load (≥ 85% of 1RM) exercises before a session, without significant VL, and with biomechanical similarity, can be beneficial for training sessions aimed at developing explosive and high-velocity movements.

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