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Research article

Impact of Training Frequency on Mechanical Output and Perceived Exertion of Resistance Training with Velocity Loss Monitoring

Zhaoqian Li [1†], Ruixuan Li [2†], Jintong Zheng [3], Zongwei Chen [1], Xing Zhang [1] and Junbei Bai [4]✉
[1] Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain; [2] School of Physical Education, China University of Geosciences (Wuhan); [3] School of Sports Medicine, Wuhan Sports University; [4] Competitive Sports No.4 Room, Beijing Research Institute of Sports Science, Beijing, China
[†] Cofirst author

Abstract
This study investigated how different weekly resistance training frequencies affect mechanical output and perceived exertion under velocity loss (VL) monitoring when the total number of sets per week was fixed. Fourteen well-trained male subjects participated in a repeated-measures design in which all participants performed three training frequency conditions (four, three, or two sessions per week) in randomized order. Each condition involved 12 total sets of back squats at 80% one repetition maximum (1RM) with a 20% VL, the total training sets evenly distributed across sessions. The results indicated that increasing training frequency allowed for lower perceived exertion ($p = 0.005$). Furthermore, the frequency of four sessions per week did not compromise velocity output or repetition performed in the following sets for within-session comparison ($p \geq 0.125$), whereas the other two frequencies resulted in compromised performance with increasing numbers of sets performed. The frequency of three sessions per week resulted in a significant decrease in the following set, as shown in the number of repetitions performed per set (N_{set}) (Δ = 8%, $p = 0.003$) and the average set mean velocity ($MV_{average}$) (Δ = 4%, $p = 0.013$) in the last set compared with the first set. The frequency of four sessions per week resulted in lower N_{set} (Δ = 17%), $MV_{average}$ (Δ = 8%), and fastest mean velocity (Δ = 7%) and last mean velocity (Δ = 9%) of the set in the last set compared with the first set ($0.001 \leq p \leq 0.033$). All training frequencies allowed adequate recovery from the frequency arrangement and did not impact performance in the subsequent session. Overall, under a fixed number of sets performed weekly, increasing training frequency helped preserve velocity output and repetitions performed within-session when using 80% 1RM and 20% VL, while also reducing perceived exertion. It is recommended that athletes distribute strength training more evenly across the week rather than concentrating it into fewer days when pursuing better mechanical output and lower perceived exertion.

Key words: Squat, training frequency, velocity-based training, velocity loss.

Introduction

Resistance training is a well-established approach to developing muscular strength, power, and hypertrophy, which are crucial for improving physical fitness and athletic performance (Scott et al. 2016). Moreover, research reveals its effectiveness in alleviating and aiding recovery from sports injuries by strengthening ligaments, tendons, and connective tissues within muscles (Fleck and Falkel 1986). To achieve maximal longitudinal outcomes of resistance training, it is crucial to carefully adjust various training parameters, including training intensity, lifting velocity, repetitions performed, inter-set rest, training volume and training frequency (Campos et al. 2002; Zhang et al. 2023). Among these factors, training frequency, referring to the number of resistance training sessions performed per week, is an inevitable factor in structuring resistance training programs with numerous studies exploring its effects (Colquhoun et al. 2018). When weekly training volume is held constant, athletes must carefully consider training frequency. A higher frequency will reduce recovery time, with potentially related following compromised performance. For example, the frequency of four sessions per week gave only 24 to 48 hours of rest time between different sessions. While after some high fatigue protocol, athletes' neuromuscular function might not recover to the baseline in the following session (Pareja-Blanco et al. 2020b). While lower frequencies, concentrating training volume into one or two sessions, can increase fatigue levels and perceived exertion (Ochi et al. 2018). Exploring the optimal training frequency in resistance training remains a compelling topic of interest.

Previous meta-analyses suggest that performing resistance training at least twice per week can help to maximize muscle hypertrophy adaptation, with around 10 repetitions per set and 10 - 20 weekly sets (Schoenfeld et al. 2016; Ralston et al. 2018). Additionally, the increase in total training volume associated with higher training frequencies contributes to greater adaptations in maximal muscle strength (Grgic et al. 2018). For team athletes, it is especially encouraged for athletes to distribute training volume across shorter, more frequent sessions within a micro-cycle, allowing for micro-dosing of strength stimuli rather than condensing volume into 1–2 weekly sessions (Cuthbert et al. 2021). However, these results and recommendations are largely based on novice trainers and traditional resistance practices. Additionally, these studies have not examined the influence of movement velocity within this context, which limits the applicability of the results, as training at maximal lifting velocity elicits greater neuromuscular stimulation and yields superior long-term adaptations (González-Badillo et al. 2014). Since traditional training methods neglect movement velocity and struggle to adjust intensity and volume based on an athlete's daily readiness, velocity-based training (VBT) was introduced to determine both training load and repetitions per set (Weak-

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ley et al. 2021; Guppy et al. 2024). Usually, training intensity is determined by the negative linear relationship between the relative one repetition maximum (1RM) and movement velocity, which can be adjusted based on the athlete's daily condition (González-Badillo and Sánchez-Medina, 2010; Chen et al. 2024; 2025). Moreover, the use of velocity loss (VL), which quantifies the decline in movement velocity relative to the fastest repetition, has proven effective in regulating repetition in the given set, mitigating fatigue levels, and achieving targeted superior outcomes compared to the traditional method which trains to failure in the set (Jukic et al. 2022). The intrinsic differences between traditional resistance training, which involves fixed loads and repetitions, and VBT, which adjusts load and repetitions based on movement velocity, suggest that frequency recommendations for traditional resistance training may not be applicable to VBT. Therefore, it is essential to incorporate training frequency into VBT considerations, as not much research examines its effect on mechanical output.

Most previous research related to VBT chooses two or three sessions of resistance training per week (Zhang et al. 2022). Meta-analysis reveals that both training frequencies significantly improved maximal strength (Ralston et al. 2018). However, the effect size of increasing 1RM was derived from different studies, involving different subjects and training protocols, so it is difficult to draw definitive conclusions about which frequency is better for improving maximal dynamic strength and other performance (Zhang et al. 2022). To the best knowledge of the authors, no other studies had compared the effects of training frequency in VBT directly. Ensuring a high level of mechanical output is a key factor in VBT, as greater movement velocity output and higher numbers of repetitions performed are beneficial for long-term training adaptations and neuromuscular capacities (Orange et al. 2020; Pareja-Blanco et al. 2020a). Specifically, the mean velocity of the concentric phase (MV) in each repetition and the number of repetitions performed are typically emphasized, as the former reflects changes in neuromuscular capacities, whereas the latter is a key determinant of training volume. Increasing training frequency may work to help improve mechanical output. As the number of sets increases, accumulating fatigue may lead to a gradual decline in velocity output and a reduced number of repetitions performed in subsequent sets (Sánchez-Medina and González-Badillo 2011; Janicijevic et al., 2024a; Martos-Arregui et al. 2024). Increasing training frequency can redistribute the remaining sets across an additional training session, thereby enhancing mechanical output performance. However, a higher training frequency inevitably reduces recovery time between sessions. Specifically, training four times per week may require athletes to perform resistance training on consecutive days, whereas training three times per week allows for a 48-hour recovery period. It remains uncertain whether the reduction in rest time due to increased training frequency affects subsequent mechanical output in submaximal loaded resistance training (Pareja-Blanco et al. 2020b; Weakley et al. 2023). Therefore, it is crucial to investigate how different training frequencies under VL monitoring, while maintaining a fixed total number of weekly training sets, influence variations in mechanical output both within and between sessions.

Therefore, the purpose of this research was to investigate the effects of changing training frequency on resistance training mechanical output and perceived exertion under a fixed number of sets and VL monitoring in the week. Specifically, we compared (1) the differences in the velocity output averaged across all training sets, perceived exertion, the number of repetitions performed, and training volume among different frequencies, and (2) the difference in velocity output and repetitions performed among different sessions (between-session: comparing the values in the given sessions across different training sessions) and sets (within-session: comparing the values in the given set between different sets within the same sessions) for the three training frequencies, separately. We hypothesize that increasing training frequency will lead to higher MV, more repetitions performed per set, greater training volume, and lower perceived exertion compared to the low frequency training program. Due to the controversial existing research, we are unable to make a hypothesis regarding the second issue.

Methods

Subjects

Fifteen male subjects volunteered to participate in this study, with fourteen completing the entire program (mean ± standard deviation [SD]; age: 20.7 ± 2.0 years; body mass: 76.1 ± 10.2 kg; height: 1.81 ± 0.08 m; parallel back squat 1RM: 145.0 ± 30.9 kg). This sample size was justified through a priori power analysis using G*Power (V.3.1.9.7, Franz Faul, Universität Kiel, Kiel, Germany). The effect size for the calculation was derived from a recent study investigating the effects of different training frequencies under volume-matched training on perceived exertion and muscle neuromuscular capacities. The analysis indicated that a minimum of ten participants was required to achieve a statistical power of 0.80 with an alpha level of 0.05 for an effect size of 1, which was indicated from the comparison of rating of perceived exertion (Ochi et al. 2018). All participants had a minimum of three years of resistance training experience and were capable of performing a full back squat with at least 130% of their body weight. None of the subjects had any musculoskeletal injuries, and they were instructed to refrain from performing any high intensity exercises throughout the study period. All subjects provided written informed consent prior to the commencement of the study. The study protocol complied with the principles outlined in the Declaration of Helsinki and was approved by the local ethics committee (2024.9.4).

Study design

A repeated-measures design was used to explore whether weekly training frequency affects the mechanical output under fixed VL monitoring and fixed numbers of training sets per week. The subjects attended the study for 10 sessions in four weeks as shown in Figure 1. The first week included one pre-session to assess 1RM of the squat (Chen et al. 2025). The following three weeks they were required to perform 12 sets of squats with 20% VL under three

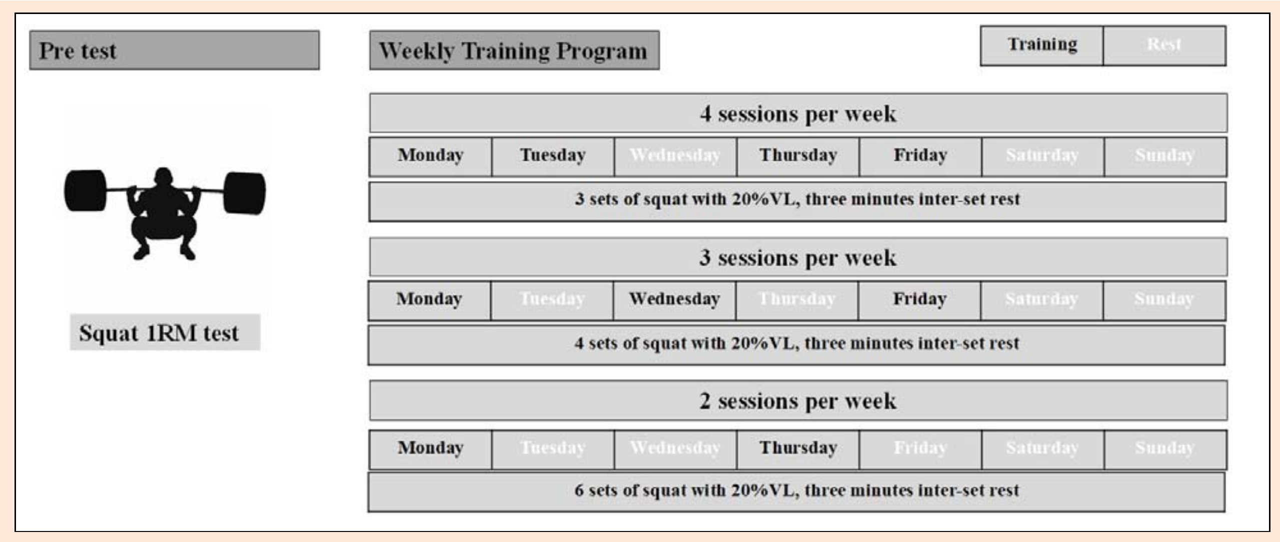

Figure 1. General overview of the study protocol. VL, velocity loss; 1RM, one repetition maximum.

different weekly training frequencies (four, three and two sessions per week), with the number of sets per session being equivalent within each frequency. Additionally, the session rating of perceived exertion (RPE) was measured 5 minutes after every training session from 1 to 10 according to Borg's CR10-Scale (Foster et al. 2001). The order of the three different frequencies was randomized.

Pre-season (One repetition maximum)

The 1RM back squat test was conducted following a standardized protocol. Subjects performed a general warm-up consisting of 5 - 10 minutes of low-intensity aerobic activity, followed by a specific warm-up with 2 - 3 sets of back squats at 50% of the estimated 1RM for 8 - 10 repetitions. Subsequently, subjects completed an incremental load test, comprising three attempts at 40% of their self-reported 1RM, three attempts at 70% of their self-reported 1RM, and one attempt at 90% of their self-reported 1RM. A maximum of five 1RM attempts were permitted for each subject, excluding the submaximal warm-up repetitions. Following a successful 1RM attempt, the external load was increased by 0.5 to 2.5 kg, based on communication with the subjects, until no further weight could be lifted. Rest periods consisted of passive recovery, with 3 minutes between different warm-up sets and 5 minutes between 1RM attempts.

Procedure

Over a three-week intervention period, participants were required to complete 12 sets of squats at 20% VL, systematically distributed across three experimental conditions: four, three, or two weekly training sessions. The training schedule was strictly controlled as follows: for the four-session frequency, participants performed three sets on Monday, Tuesday, Thursday, and Friday; for the three-session frequency, four sets were completed on Monday, Wednesday, and Friday; and for the two-session frequency, six sets were performed on Monday and Thursday. To ensure experimental rigor, all training sessions across different frequencies were conducted at the same time of day (±1 hour) under standardized environmental conditions (temperature: 22 ± 1°C; humidity: 50 ± 5%). Participants were instructed to maintain their habitual dietary patterns while abstaining from caffeine consumption for 12 hours preceding each session. Additionally, they were required to refrain from any additional resistance training or strenuous physical activity throughout the study period, with compliance monitored through daily activity logs and weekly interviews.

Each training session began with a general warm-up consisting of jogging, dynamic stretching, and several countermovement jumps, followed by a specific warm-up involving submaximal squats with light loads performed at maximal intended velocity. Subjects then performed the assigned sets of squats at 80% 1RM with 20% VL, with a three-minute rest between sets. Participants assumed an initial upright stance with neutral hip and knee alignment, maintaining a shoulder-width base of support. The barbell was positioned across the superior trapezius region. Upon receiving the investigator's verbal cue "squat", subjects initiated the eccentric phase using a self-determined cadence (≈1.2s) until achieving femoral parallel alignment relative to the ground plane. Utilizing the stretch-shortening cycle, participants were instructed to explosively transition into the concentric phase with maximal volitional effort.

The MV was measured using the Chronojump system (Chronojump-Boscosystem, Barcelona, Spain), which was calculated as the mean velocity from the beginning of the concentric phase until the load reached its maximum height. The Chronojump linear positional transducer was positioned on the ground to the right of the subjects' feet, with the Velcro strap attached 0.5m to the right of the barbell center. The VL was calculated as the percentage decrease in MV from the fastest repetition to the last repetition in each set, which was automatically achieved by the application. Sets were terminated once the prescribed VL was reached. After 5 minutes finishing the training session, the session RPE was rated from 1 to 10 according to Borg's CR10-Scale (Foster et al. 2001). The order of the three different frequencies was randomized.

Data preprocessing

The number of repetitions performed in each set (N_{set}) and each session ($N_{session}$) were recorded. Training volume in each session ($V_{session}$) and each week (V_{week}) were calculated by multiplying load and corresponding repetitions performed. The mean fastest MV of the set ($MV_{Fastest}$), the average MV of the set from all repetitions ($MV_{average}$), and the MV of the last repetition of the set (MV_{last}) were recorded. The average RPE, $N_{session}$, and $V_{session}$ were calculated as the average across all sessions within the same training frequencies. The average set N_{set}, $MV_{Fastest}$, $MV_{average}$, and MV_{last} were calculated across all sets within the same training frequencies. To quantify the variations between different sets within training sessions, the average value of the set from different sessions was calculated first, then within-session Coefficient of Variation (CV, standard error of measurement/subjects' mean score × 100) based on the average value from different sets of each subject was calculated for N_{set}, $MV_{Fastest}$, $MV_{average}$, and MV_{last} in different training frequencies. To quantify the variations between different sessions, the average value of the set from the same sessions was calculated first, then the between-session CV based on the average value from different sessions of each subject was calculated for N_{set}, $MV_{Fastest}$, $MV_{average}$, and MV_{last} in different training frequencies.

Statistical analyses

Descriptive data are expressed as means ± SD. The normality of the variables was confirmed using the Shapiro - Wilk test ($p > 0.05$). To compare the mechanical output and perceived exertion between different training frequencies, one-way repeated measures analyses of variance (ANOVAs) were employed to compare the average session RPE, average set $MV_{Fastest}$, $MV_{average}$, MV_{last}, N_{set}, and average $N_{session}$, $V_{session}$, and V_{week} across different training frequencies. To compare the training outcomes in each training frequencies between different sessions and sets, two-way repeated measures ANOVA (between-session × within-session) was employed to compare average set $MV_{Fastest}$, $MV_{average}$, MV_{last}, and N_{set} for different training frequencies separately. Two separate two-way repeated measures ANOVAs (Variables × frequencies) comparing the CVs in different conditions for within-session and between-session separately. Mauchly's Test of Sphericity was conducted to evaluate the assumption of sphericity for the repeated measures ANOVA. If the sphericity assumption was violated ($p < 0.05$), the Greenhouse-Geisser correction was applied to adjust the degrees of freedom. All statistical analyses were performed using SPSS software version 22.0 (SPSS Inc., Chicago, IL, USA) and statistical significance was set at an alpha level of 0.05 or less.

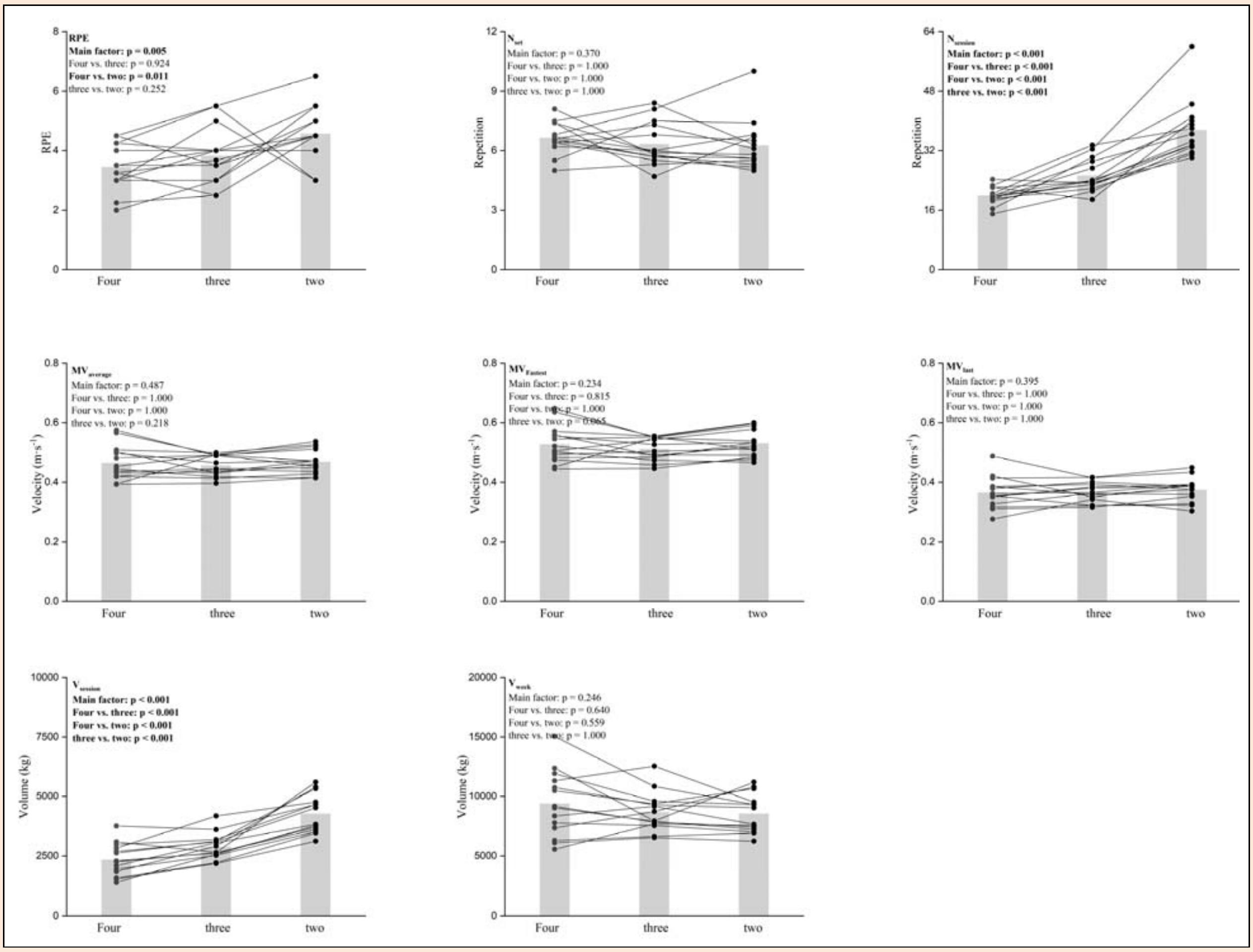

Figure 2. Comparison of mechanical variables across training sessions with different frequencies. Upper panel from left to right: Rating of Perceived Exertion (RPE), number of repetitions performed per set (N_{set}), number of repetitions performed per session ($N_{session}$); middle panel from left to right: average set mean velocity ($MV_{average}$), fastest mean velocity ($MV_{fastest}$), mean velocity of the last repetition (MV_{last}) from all training sets; lower panel from left to right: training volume of the session ($V_{session}$), training volume of the week (V_{week}).

Results

Significant effects were found between session RPE, $N_{session}$, and $V_{session}$ ($F \geq 6.428$, $p \leq 0.005$) but not in N_{set}, V_{week} and MV-related metrics ($MV_{Fastest}$, $MV_{average}$, MV_{last}) ($F \leq 2.182$, $p \geq 0.135$). Pairwise comparisons revealed significant differences in all cases for $N_{session}$ and $V_{session}$, with the frequency of 2 sessions per week yielding higher values than those of both 3 and 4 sessions, and the frequency of 3 sessions also showing higher values than that of 4 sessions. Pairwise comparisons revealed that the training frequency of 4 times per week led to significantly lower session RPE compared to that of 2 times per week, but not significantly compared to that of 3 times per week (Figure 2).

Between-session effects and interaction effects did not reach statistical significance under any of the three training frequencies ($p \geq 0.095$). No significant difference was found for within-session comparison in the frequency of 4 times per week for all mechanical output variables ($p \geq 0.125$) (Table 1). However, at the frequency of three sessions per week, significant within-session effects were found for $MV_{average}$ and N_{set} ($p \leq 0.013$), although no significant pairwise differences were observed (Table 2). For the frequency of two times per week, the within-session effects showed significant differences in all variables ($p \leq 0.033$). Significant pairwise difference was found in $MV_{average}$, $MV_{fastest}$ between set 1, set 2 and set 6, and also in MV_{last} between set 2 and set 6 (Table 3).

Table 1. Comparison of mechanical outputs within and between sessions in the frequency of 4 times per week.

Variables	Session	Set 1	Set 2	Set 3	Average	ANOVA
$MV_{average}$ ($m \cdot s^{-1}$)	Session1	0.47 ± 0.06	0.46 ± 0.06	0.45 ± 0.06	0.46 ± 0.06	B: p = 0.301 W: p = 0.125 Interaction: p = 0.994
	Session2	0.47 ± 0.06	0.46 ± 0.07	0.45 ± 0.07	0.46 ± 0.06	
	Session3	0.48 ± 0.07	0.47 ± 0.07	0.47 ± 0.07	0.47 ± 0.07	
	Session4	0.48 ± 0.06	0.47 ± 0.07	0.46 ± 0.06	0.47 ± 0.07	
	Average	0.47 ± 0.06	0.47 ± 0.06	0.46 ± 0.06		
$MV_{fastest}$ ($m \cdot s^{-1}$)	Session1	0.53 ± 0.07	0.52 ± 0.07	0.51 ± 0.07	0.52 ± 0.07	B: p = 0.442 W: p = 0.890 Interaction: p = 0.613
	Session2	0.52 ± 0.07	0.53 ± 0.08	0.52 ± 0.07	0.52 ± 0.07	
	Session3	0.54 ± 0.08	0.53 ± 0.06	0.55 ± 0.10	0.54 ± 0.07	
	Session4	0.54 ± 0.06	0.54 ± 0.08	0.55 ± 0.11	0.53 ± 0.07	
	Average	0.51 ± 0.06	0.53 ± 0.06	0.53 ± 0.07		
MV_{last} ($m \cdot s^{-1}$)	Session1	0.37 ± 0.07	0.36 ± 0.08	0.37 ± 0.06	0.37 ± 0.06	B: p = 0.851 W: p = 0.436 Interaction: F = 0.270, p = 0.949
	Session2	0.37 ± 0.07	0.36 ± 0.06	0.35 ± 0.08	0.36 ± 0.06	
	Session3	0.38 ± 0.08	0.37 ± 0.09	0.36 ± 0.08	0.37 ± 0.07	
	Session4	0.37 ± 0.07	0.38 ± 0.06	0.36 ± 0.05	0.37 ± 0.05	
	Average	0.37 ± 0.04	0.37 ± 0.06	0.36 ± 0.06		
N_{set} (n)	Session1	6.3 ± 2.2	6.8 ± 1.3	6.7 ± 1.4	6.6 ± 1.1	B: p = 0.095 W: p = 0.677 Interaction: p = 0.214
	Session2	7.1 ± 2.1	6.3 ± 1.6	6.5 ± 1.6	6.6 ± 1.3	
	Session3	7.0 ± 1.3	7.4 ± 2.0	7.1 ± 2.1	7.2 ± 1.3	
	Session4	5.6 ± 1.7	6.2 ± 1.5	6.9 ± 1.6	6.3 ± 1.1	
	Average	6.5 ± 1.1	6.7 ± 1.0	6.8 ± 1.1		

$MV_{average}$, average mean velocity per set; $MV_{fastest}$, fastest mean velocity per set; MV_{last}, last mean velocity per set; N_{set}, number of repetitions completed per set. B, between-session comparison; W, within-session comparison; Bold numbers indicate *p* values below 0.05.

Table 2. Comparison of mechanical outputs within and between sessions in the frequency of 3 times per week.

Variables	Session	Set 1	Set 2	Set 3	Set 4	Average	ANOVA
$MV_{average}$ ($m \cdot s^{-1}$)	Session1	0.46 ± 0.05	0.46 ± 0.04	0.44 ± 0.04	0.43 ± 0.04	0.45 ± 0.04	B: p = 0.220 **W p = 0.003** Interaction: p = 0.236
	Session2	0.46 ± 0.04	0.47 ± 0.05	0.46 ± 0.05	0.46 ± 0.06	0.46 ± 0.04	
	Session3	0.48 ± 0.06	0.46 ± 0.06	0.46 ± 0.05	0.45 ± 0.06	0.46 ± 0.05	
	Average	0.47 ± 0.04	0.46 ± 0.04	0.45 ± 0.04	0.45 ± 0.04		
$MV_{fastest}$ ($m \cdot s^{-1}$)	Session1	0.52 ± 0.04	0.53 ± 0.05	0.52 ± 0.05	0.51 ± 0.07	0.52 ± 0.05	B p = 0.142 W: p = 0.062 Interaction: p = 0.090
	Session2	0.54 ± 0.06	0.51 ± 0.06	0.52 ± 0.05	0.51 ± 0.06	0.51 ± 0.06	
	Session3	0.54 ± 0.06	0.51 ± 0.06	0.52 ± 0.05	0.501± 0.06	0.52 ± 0.05	
		0.52 ± 0.04	0.51 ± 0.04	0.51 ± 0.04	0.50 ± 0.05		
MV_{last} ($m \cdot s^{-1}$)	Session1	0.39 ± 0.06	0.37 ± 0.06	0.36 ± 0.04	0.35 ± 0.04	0.37 ± 0.04	B: p = 0.989 W: p = 0.102 Interaction: p = 0.275
	Session2	0.38 ± 0.06	0.35 ± 0.10	0.37 ± 0.05	0.37 ± 0.06	0.36 ± 0.05	
	Session3	0.38 ± 0.07	0.37 ± 0.05	0.37 ± 0.05	0.35 ± 0.08	0.37 ± 0.06	
		0.38 ± 0.04	0.36 ± 0.05	0.36 ± 0.04	0.36 ± 0.04		
N_{set} (n)	Session1	6.9 ± 2.6	6.5 ± 2.9	5.5 ± 2.3	6.2 ± 2.5	6.3 ± 1.9	B: p = 0.996 **W: p = 0.013** Interaction: p = 0.350
	Session2	6.3 ± 1.6	6.4 ± 1.8	6.4 ± 2.1	6.2 ± 1.9	6.3 ± 1.2	
	Session3	6.7 ± 1.7	6.3 ± 0.8	6.4 ± 1.6	5.8 ± 1.5	6.3 ± 0.7	
		6.6 ± 1.4	6.4 ± 1.1	6.1 ± 1.1	6.1 ± 1.4		

$MV_{average}$, average mean velocity per set; $MV_{fastest}$, fastest mean velocity per set; MV_{last}, last mean velocity per set; N_{set}, number of repetitions completed per set; B, between-session comparison; W, within-session comparison; Bold numbers indicate *p* values below 0.05. a indicates significant difference from 4 Set 1.

Table 3. Comparison of mechanical outputs within and between sessions in the frequency of 2 times per week.

Variables	Session	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Average	ANOVA
$MV_{average}$ ($m \cdot s^{-1}$)	Session1	0.48 ± 0.05	0.49 ± 0.04	0.47 ± 0.05	0.46 ± 0.05	0.45 ± 0.04	0.44 ± 0.05	0.46 ± 0.04	B: p = 0.476
	Session2	0.49 ± 0.04	0.48 ± 0.05	0.48 ± 0.05	0.48 ± 0.05	0.46 ± 0.07	0.44 ± 0.07	0.47 ± 0.05	**W: p < 0.001**
	Average	0.48 ± 0.04	0.48 ± 0.04	0.48 ± 0.04	0.47 ± 0.04	0.46 ± 0.05	0.44 ± 0.05 ^{a,b}		Interaction: p = 0.929
$MV_{fastest}$ ($m \cdot s^{-1}$)	Session1	0.55 ± 0.05	0.55 ± 0.05	0.54 ± 0.05	0.52 ± 0.06	0.51 ± 0.05	0.51 ± 0.06	0.53 ± 0.04	B: p = 0.552
	Session2	0.55 ± 0.05	0.55 ± 0.06	0.54 ± 0.06	0.53 ± 0.05	0.53 ± 0.08	0.51 ± 0.07	0.53 ± 0.06	**W: p < 0.001**
	Average	0.55 ± 0.04	0.55 ± 0.04	0.54 ± 0.04	0.53 ± 0.05	0.52 ± 0.06	0.51 ± 0.06 ^{a,b}		Interaction: p = 0.854
MV_{last} ($m \cdot s^{-1}$)	Session1	0.40 ± 0.06	0.38 ± 0.07	0.35 ± 0.06	0.37 ± 0.06	0.37 ± 0.05	0.34 ± 0.06 ^{b}	0.37 ± 0.05	B: p = 0.243
	Session2	0.38 ± 0.07	0.41 ± 0.04	0.39 ± 0.06	0.38 ± 0.06	0.36 ± 0.08	0.36 ± 0.08	0.38 ± 0.05	**W: p = 0.033**
	Average	0.39 ± 0.04	0.40 ± 0.05	0.37 ± 0.06	0.38 ± 0.05	0.36 ± 0.06	0.35 ± 0.06		Interaction: p = 0.271
N_{set} (n)	Session1	7.0 ± 2.3	6.5 ± 2.0	7.0 ± 2.5	6.4 ± 2.4	5.6 ± 2.6	5.6 ± 1.6	6.3 ± 1.5	B: p = 0.919
	Session2	7.1 ± 2.5	6.2 ± 2.3	6.7 ± 2.2	5.6 ± 1.6	6.0 ± 2.2	5.9 ± 2.4	6.3 ± 1.6	**W: p = 0.013**
	Average	7.0 ± 2.5	6.4 ± 2.3	6.9 ± 2.2	5.9 ± 1.5	5.7 ± 2.2	5.8 ± 2.4		Interaction: p = 0.718

$MV_{average}$, average mean velocity per set; $MV_{fastest}$, fastest mean velocity per set; MV_{last}, last mean velocity per set; N_{set}, number of repetitions completed per set. B, between-session comparison; W, within-session comparison; Bold numbers indicate *p* values below 0.05. a indicates significant difference from set 1, b indicates significant difference from set 2.

Table 4. Comparsion of within-set and within-session fluctuation among different variables and different training frequencies.

Condition	Variables	CV, % 4 sessions	CV, % 3 sessions	CV, % 2 sessions^{a,b}	ANOVA
Within-Session	$MV_{average}$	2.6 ± 1.8	3.5 ± 2.1	5.5 ± 2.6	**Frequency: p < 0.001**
	$MV_{fastest}$	2.9 ± 1.1	3.7 ± 1.9	5.3 ± 2.4	**Variables: p < 0.001**
	$MV_{last}^{x,y}$	5.3 ± 3.4	7.4 ± 5.3	10.1 ± 4.5	**Interaction: p < 0.001**
	$N_{set}^{x,y,z}$	10.8 ± 3.9	12.4 ± 5.9	23.3 ± 9.7	
		4 sessions	**3 sessions**	**2 sessions**	
Between-Session	$MV_{average}$	5.6 ± 3.8	6.0 ± 2.9	4.0 ± 3.1	Frequency: p = 0.204
	$MV_{fastest}$	8.0 ± 7.2	5.8 ± 2.9	3.9 ± 3.1	**Variables: p < 0.001**
	$MV_{last}^{x,y}$	8.3 ± 5.3	9.5 ± 7.5	6.6 ± 3.1	Interaction: p = 0.747
	$N_{set}^{x,y,z}$	14.0 ± 5.2	15.9 ± 0.7	14.4 ± 13.1	

CV, coefficient of varaition; $MV_{average}$, average mean velocity per set; $MV_{fastest}$, fastest mean velocity per set; MV_{last}, last mean velocity per set; N_{set}, number of repetitions completed per set. Bold numbers indicate *p* values below 0.05. a indicates significant difference from the frequency of 4 sessions, b indicates significant difference from the frequency of 3 sessions. x indicates significant difference from $MV_{average}$, y indicates significant difference from $MV_{fastest}$, z indicates significant difference from MV_{last}.

Significant effects of frequency, variables and interaction factors were found for within-session CV comparison ($F \geq 6.754$, $p < 0.001$) and for the significant variable factors in between-session comparison ($F = 28.820$, $p < 0.001$). Significant pairwise differences were found in the frequency of 4 sessions and 3 sessions per week compared to that of 2 sessions for within-session comparison, which indicated that the mechanical output in the frequency of 2 sessions per week had a bigger fluctuation due to the compromised performance from accumulated fatigue in the following set compared with other frequencies. Significant pairwise differences were also found between $MV_{average}$, and $MV_{fastest}$ compared with MV_{last} and N_{set} for both within-session CV and between-session CV (Table 4).

Discussion

This study was the first one that aimed to investigate the effects of different training frequencies on mechanical output and perceived exertion under VL monitoring with a fixed number of sets. Fourteen well-trained males performed 12 sets of squats at 80%1RM with a 20% VL in three different frequencies. The one-way ANOVA results showed that training at a frequency of 4 sessions per week resulted in lower session RPE from lower $N_{session}$ and $V_{session}$. The non-significant between-session comparison revealed that all frequencies could provide enough recovery time because the mechanical output in the following sessions was not significantly different and affected, although their interval time was different. The within-session comparison showed that the frequency of 4 sessions did not compromise the mechanical output in the following sets, but those of 2 and 3 sessions per week reduced the mechanical output. Compared with the frequency of 3 sessions and 2 sessions per week, the frequency of 4 sessions did not compromise the mechanical output in the following sets and reported the lowest within-session fluctuation. This indicated that the frequency of four sessions per week resulted in a smaller decline in mechanical output within a given session, whereas the frequencies of three and two sessions per week exhibited a more pronounced reduction in mechanical output when comparing the later sets to the earlier ones within the same session. There was a significant difference for within-session comparison among the different training frequencies rather than between-session comparison. This suggested that, across different training frequencies, the primary differences lie in the extent of compromised mechanical output within sessions, rather than in the recovery status between sessions.

From the session perspective, increasing weekly training frequency reduced the $N_{session}$ and $V_{session}$ per session under fixed numbers of sets, subsequently reducing perceived exertion per session. This difference was most pronounced between the training frequency of 4 sessions per week compared to that of 2 sessions, with four weekly sessions reducing subjective perceived exertion by 24%. The reduced perceived exertion following resistance training may minimize interference effects on subsequent training sessions, thereby enhancing overall training efficiency and facilitating more effective training schedule management (Pageaux 2016; Janicijevic et al., 2024a). Common training strategies, such as the Bulgarian Method and Microdosing, emphasize distributing the total training volume more frequently across daily sessions (Takano, 1989; Cuthbert et al. 2024). Our experiment supports these approaches and their underlying principles in VBT, which seek better mechanical output and lower perceived exertion. Distributing a fixed number of training sets across more sessions could help to achieve it. Although our experiment did not reveal any significant differences in N_{set} or V_{week} across different frequencies, there were slight increases in N_{set} and V_{week} associated with higher frequency. For example, athletes could perform 10% V_{week} more for the frequency of 4 sessions compared with that of 2 sessions. A reduced number of sets per session could effectively mitigate fatigue accumulation across consecutive sets, while simultaneously enhancing athletes' psychological readiness and confidence to execute the training program with optimal performance quality. Based on existing long-term studies, it could be inferred that altering training frequency, which results in potentially more training volume maintained at high-velocity levels, contributes to better improvements in velocity-related performance (Rodríguez-Rosell et al., 2021; Rodiles-Guerrero et al., 2022).

We noted that only the frequency of 4 times per week maintained the mechanical outputs in the following sets. The frequency of 3 times per week could not keep the $MV_{average}$ and N_{set} in the following set, leading to around 4% decrement for the $MV_{average}$ and 7% for N_{set} compared with the peak value. The training frequency of 2 times per week resulted in compromised mechanical output across all variables, with a reduction of approximately 8% in velocity output and 1.2 fewer repetitions compared to the first set. Similar results have also been reported in previous studies (Janicijevic et al., 2024a; Martos-Arregui et al., 2024). With the increasing number of sets and the rise in perceived exertion during the training session, mechanical output was inevitably compromised to some extent. To address this, former research proposed that extending rest intervals (González-Hernández et al. 2023; Janicijevic et al., 2024b), adjusting the load intensity (Banyard et al. 2019; Weakley et al. 2020), and incorporating assistive devices (Jukic et al., 2023a; Miras-Moreno et al. 2024) to help sustain high movement velocities. Our findings suggest that increasing the frequency of training could also be a useful strategy for maintaining mechanical output. The frequency of four sessions per week reduced perceived exertion, as indicated by lower RPE compared to other frequency conditions. This frequency also provided less compromised mechanical output in the following set within each session compared with other frequencies.

No significant effects for between-session comparison and its interaction effects with within-session comparison, indicating that athletes were able to recover from the previous session in all arrangements. The frequency of 3 and 2 times per week provided athletes with 48 to 72 hours of rest, which was clearly sufficient for 80%1RM squat with 20% VL training schedules (Pareja-Blanco et al. 2019). The importance of our study lay in reporting that well-trained athletes could recover from 3 sets of 80% 1RM squats with 20%VL within 24 hours, which was crucial for scheduling 4 training sessions per week, as this frequency required consecutive strength training within a two-day period. Previous investigations have predominantly focused on the recovery patterns of maximal strength and velocity capabilities, while largely neglecting the performance of muscular endurance (Pareja-Blanco et al. 2019; Weakley et al. 2023). Our experimental findings provided further evidence that, in addition to the recovery of movement velocity under submaximal load conditions, the neuromuscular system's capacity to maintain mechanical output at predetermined velocity can be fully restored within a 24-hour recovery period. This finding demonstrated the feasibility of distributing a prescribed training set with VL monitoring across four weekly sessions, as this training frequency did not compromise mechanical output parameters in subsequent training sessions.

The significant influence of training frequency on within-session CV revealed different levels of mechanical output decline, which were directly associated with the varying number of sets performed per session due to changing frequencies. Specifically, the frequency of two sessions per week, which required performing 6 sets per session, showed the greatest fluctuation and decline compared to that of 3 sessions and 4 sessions per week. Furthermore, no significant effect of frequency was observed in between-session comparisons, demonstrating that performance in subsequent sessions did not substantially differ from the first session. Indeed, the mean values indicate minimal differences across sessions, which further might provide that all implemented training frequencies provided adequate recovery intervals between sessions to ensure the maintenance of mechanical output stability.

In addition, we identified significant effects of training variables on both between-session and within-session comparisons. Notably, the fluctuation of $MV_{average}$ and $MV_{fastest}$ was the lowest in both within-session and between-session level, consistent with previous studies that identified these as critical variables reflecting the quality of resistance training (Miras-Moreno et al., 2022; Jukic et al., 2023a). Conversely, N_{set} showed the highest fluctuation in both within-session and between-session, which aligned with earlier research questioning its stability under VL monitoring (Jukic et al., 2023b). However, the fluctuation for the within-session level could still be reduced through increasing training frequencies.

This experiment was the first to investigate how different training frequencies affected mechanical output in the context of VBT; however, some inherent limitations must be acknowledged. Firstly, our research performed an acute experiment, which did not necessarily imply that the potentially superior mechanical output would result in improved athletic performance in long-term interventions. Secondly, we only included lower limb training; however, in practice, athletes typically engage in both upper and lower limb training. The question of how to reasonably allocate upper and lower limb exercises under VL monitoring remains unanswered. Additionally, given fatigue was more affected by VL rather than the number of sets (Weakley et al. 2019; 2023), our program with 20%VL might not be the perfect design to promise velocity output and repetitions performed. Finally, the results of this experiment are limited to young, male, trained individuals. Given that recovery was influenced by factors such as gender, status, and other variables, these findings cannot be broadly generalized arbitrarily.

Conclusion

Compared to the frequency of two training sessions with six sets per session, higher-frequency training with fewer sets per session could help to reduce perceived exertion (around 24%) under the same number of sets per week. Additionally, increasing training frequency was a practical strategy to maintain velocity output (reduce less than 2%) and repetitions (reduce less than 3%) performed of the following set in the same session. Moreover, the reduction in training set per session resulting from increased training frequency enabled athletes to fully recover from previous resistance training sessions, thereby maintaining consistent mechanical output in subsequent sessions without compromising performance. Therefore, for weekly strength training scheduling, strength and conditioning coaches may consider implementing more frequent but lower-volume sessions. This approach can help reduce within-session fatigue and reduce its impact on subsequent training sessions. However, these findings were observed under controlled conditions (12 sets of squats with 20%VL per week), athletes often faced complicated situations in the training applications, which can contribute to additional fatigue and variability. Future research should investigate the effectiveness of this strategy within comprehensive training programs.

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Key points

- Different training frequencies with a fixed number of weekly sets under velocity loss (VL) monitoring lead to slightly different training results.
- A higher training frequency helps to maintain movement velocity and the number of repetitions performed per set under VL monitoring.
- Spreading the same number of training sets over more training sessions results in less perceived exertion.

AUTHOR BIOGRAPHY

Zhaoqian LI
Employment
Department of Physical Education and Sport, Faculty of Sport. Sciences, University of Granada, Granada. Spain.
Degree
M.Sc.
Research interests
Research on Velocity-Based Training and Force-Velocity relationship
E-mail: lzqf3ng@gmail.com

Ruixuan LI
Employment
Laboratory of Sports Human Science, School of Physical Education, China University of Geosciences (Wuhan)
Degree
B.Ed.
Research interests
Strength Training; Load-Velocity Relationship; Velocity-Based Training
E-mail: 2101523729@qq.com

Jintong ZHENG
Employment
College of Sports Medicine, Wuhan sports University
Degree
B.Sc.
Research interests
Strength and Conditioning; Load-Velocity Relationship; Velocity-Based Training
E-mail: 3576561532@qq.com

Zongwei CHEN
Employment
Department of Physical Education and Sport, Faculty of Sport. Sciences, University of Granada, Granada. Spain.
Degree
M.Ed.
Research interests
Strength & conditioning; Velocity-Based Training
E-mail: 2022021047@m.scnu.edu.cn

Xing ZHANG
Employment
Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada. Spain.
Degree
M.Ed.
Research interests
Exercise science, Public health, and Cyberpsychology
E-mail: starz@correo.ugr.es

Junbei BAI
Employment
Competitive Sports No.4 Room, Beijing Research Institute of Sports Science, Beijing, China
Degree
Ph.D.
Research interests
Sports physiology, Hypoxia training, Breathing muscle training
E-mail: baijunbei@hotmail.com

✉ **Junbei Bai**
Competitive Sports No.4 Room, Beijing Research Institute of Sports Science, Beijing, China