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ORIGINAL ARTICLE

Resistance training intensity and volume affect changes in rate of force development in resistance-trained men

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Abstract

Purpose To compare the effects of two different resistance training programs, high intensity (INT) and high volume (VOL), on changes in isometric force (FRC), rate of force development (RFD), and barbell velocity during dynamic strength testing.

Methods Twenty-nine resistance-trained men were randomly assigned to either the INT ($n = 15$, 3–5 RM, 3-min rest interval) or VOL ($n = 14$, 10–12 RM, 1-min rest interval) training group for 8 weeks. All participants completed a 2-week preparatory phase prior to randomization. Measures of barbell velocity, FRC, and RFD were performed before (PRE) and following (POST) the 8-week training program. Barbell velocity was determined during one-repetition maximum (1RM) testing of the squat (SQ) and bench press (BP) exercises. The isometric mid-thigh pull was used to assess FRC and RFD at specific time bands ranging from 0 to 30, 50, 90, 100, 150, 200, and 250 ms.

Results Analysis of covariance revealed significant ($p < 0.05$) group differences in peak FRC, FRC at 30–200 ms, and RFD at 50–90 ms. Significant ($p < 0.05$) changes in INT but not VOL in peak FRC (INT: 9.2 ± 13.8 %; VOL: −4.3 ± 10.2 %), FRC at 30–200 ms (INT: 12.5–15.8 %; VOL: −1.0 to −4.3 %), and RFD at 50 ms (INT: 78.0 ± 163 %; VOL: −4.1 ± 49.6 %) were observed. A trend ($p = 0.052$) was observed for RFD at 90 ms (INT: 58.5 ± 115 %; VOL: −3.5 ± 40.1 %). No group differences were observed for the observed changes in barbell velocity.

Conclusions Results indicate that INT is more advantageous than VOL for improving FRC and RFD, while changes in barbell velocity during dynamic strength testing are similarly improved by both protocols in resistance-trained men.

Keywords Rate of force development · Bench press velocity · Back squat velocity · Isometric strength

Abbreviations

ANCOVA	Analysis of covariance
AUC	Area under the curve
SQ	Back squat
BP	Bench press
FRC	Force
INT	High-intensity, low-volume training group
VOL	High-volume, moderate-intensity training group
HPL	Human-Performance Laboratory
ICC	Intraclass correlation coefficient
MDL	Minimal difference
1RM	One-repetition maximum
POST	Post-testing
PRE	Pre-testing
RFD	Rate of force development
SEM	Standard error of the measurement

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Introduction

In resistance-trained populations, assessing changes in strength is important for determining the effect and benefit of a resistance training program (Hoffman 2014; Ratamess et al. 2009). Strength is often assessed in one or more of the core exercises (e.g., bench press, back squat) of the training program. Success in these lifts hinges upon the rate in which the athlete can produce sufficient force to overcome the external load's inertia and accelerate that load in the desired direction (Flanagan 2013). This ability is first governed by the number and size of the athlete's active muscle fibers and then by how frequently he/she can activate those fibers (Flanagan 2013; Ratamess et al. 2009). Since it is believed that muscle fibers are progressively activated from the smallest (i.e., Type I) to the largest (i.e., Type II) fibers (Henneman et al. 1965), and the largest muscle fibers produce the most force and contract with the greatest velocity (D'Antona et al. 2006), the rapidity in which the largest fibers are utilized [i.e., rate of force development (RFD)] would seem to be relevant to the success of a lift. Nevertheless, studies on RFD and one-repetition maximum (1RM) strength have shown inconsistent relationships (McGuigan et al. 2010; McGuigan and Winchester 2008; Wang et al. 2016). For example, peak RFD measured during an isometric mid-thigh pull was not found to be related to 1RM strength (McGuigan et al. 2010; McGuigan and Winchester 2008). However, others have observed moderate-to-strong relationships (r = 0.60–0.75) to 1RM strength when RFD was measured within specific time epochs (90–250 ms) of the mid-thigh pull (Wang et al. 2016). Others have demonstrated that resistance training can promote comparable increases in strength and RFD when it is measured during the late phase (150–250 ms) (Aagaard et al. 2002; Häkkinen et al. 1981). Thus, it appears that adaptations in RFD, as they relate to dynamic strength, are phase-specific.

An additional consideration that may be related to the success of a lift is barbell velocity during the concentric contraction. When a load is traveling at a greater velocity, it has more momentum and is therefore more resistant to deceleration (Flanagan 2013). This translates to force being expressed at a higher velocity (i.e., mechanical power) and improves the likelihood of reaching a mechanically advantaged position. Similar to greater force production, greater contraction velocity is indicative of larger muscle fiber activation (D'Antona et al. 2006), and may coincide with changes in RFD. Unfortunately, measuring changes in barbell velocity during strength testing is difficult due to the use of different resistance loads being used across testing sessions. For instance, a recent investigation reported limited adaptations in power following training despite significant improvements in strength (Naclerio et al. 2013). In that study, the highest average power, measured during several submaximal attempts in the bench press, squat, and upright row exercises leading up to a 1RM, was used for analysis. Since strength significantly changed across training, the value of these testing loads also changed, making it unclear whether differences in power were related to differences in force input, and/or barbell velocity. Therefore, the ability to detect changes in high-velocity movement appears to be greater when the testing load is controlled.

It is well-established that resistance training can lead to adaptations in several strength characteristics, but the type and magnitude of such improvements are specific to the design of the training program (Haff and Nimphius 2012; Ratamess et al. 2009). For example, greater strength improvements typically occur in trained adults when using near-maximal loads (Heggelund et al. 2013; Mangine et al. 2015), while high-velocity movements (i.e., ballistic or with ballistic intent) are generally more useful for optimizing RFD and bar velocity (i.e., mechanical power) (Cormie et al. 2010; Hoffman et al. 2004; Mangine et al. 2008; Vissing et al. 2008). Still, if improving an array of strength characteristics is the goal, including a combination of both high-intensity and high-velocity exercises may be most beneficial (Hoffman et al. 2004; Mangine et al. 2008). Although evidence does suggest that training specificity is beneficial for maximizing adaptations, several considerations (e.g., progression strategy, training for multiple goals, facility and equipment, time constraints, and so on) are likely to affect optimal programming within a specific training cycle. Therefore, an understanding of the potential adaptations from different training paradigms appears to be important.

Previous studies examining adaptations to RFD and high-velocity movement following resistance training have predominantly focused on either a single training scheme (Aagaard et al. 2002; Oliveira et al. 2013a, b) or compared traditional programming to protocols that included specific high-velocity components (Cormie et al. 2010; Hoffman et al. 2004; Mangine et al. 2008; Vissing et al. 2008). However, information comparing traditional resistance training paradigms (i.e., programs without specific high-velocity exercises) on these types of adaptations is limited. When comparing single versus multiple-set training schemes, similar adaptations in RFD and high velocity have been observed (Marshall et al. 2011; Naclerio et al. 2013), while others have concluded that higher intensity loads (4–5 RM vs. 10 RM) were more effective for developing RFD (Heggelund et al. 2013). Higher intensity loads are believed to better activate larger muscle fibers that are responsible for the greatest force production and high-velocity movement (D'Antona et al. 2006; Henneman et al. 1965). In contrast, the lower intensity loads, used in conjunction with high-volume resistance training, are typically performed at greater velocities (Hoffman

2014; Ratamess et al. 2009; Zink et al. 2006), a characteristic thought to be more beneficial for developing RFD and high-velocity movement (Haff and Nimphius 2012; Ratamess et al. 2009). Thus, the primary aim of the present investigation was to compare adaptations in RFD and barbell velocity during dynamic strength testing following a traditional moderate-intensity, high-volume resistance training program or a traditional high-intensity, low-volume program in resistance-trained men. We hypothesize that the high-intensity training program will have a greater effect on improvements in force production, RFD, and barbell velocity.

Methods

Experimental design

To ensure each participant initiated the study with a comparable training base, all participants were required to complete a 2-week preparatory training program. During this phase, four participants removed themselves from the study for reasons unrelated to the investigation. Participants were then randomly assigned to one of two training groups: a high-intensity, low-volume training group (INT; $n = 15$; 24.7 ± 3.4 years; 90.0 ± 15.3 kg; 179.5 ± 5.6 cm) or a high-volume, moderate-intensity training group (VOL; $n = 14$; 24.0 ± 2.7 years; 90.1 ± 11.7 kg; 169.9 ± 29.0 cm). Participants were assessed at the conclusion of the preparatory period (PRE) and following 8 weeks of training (POST). All testing occurred during a standard time of day similar to each participant's training schedule. Assessments included anthropometry, isometric force, and velocity testing. The 8-week resistance training program (4 sessions week^{-1}) was performed under the direct supervision of certified strength and conditioning specialists.

Participants

Thirty-three physically active, resistance-trained men who had been regularly participating in resistance training for a minimum of 2 years (5.7 ± 2.2 years) and free of any physical limitations (determined by medical history questionnaire and PAR-Q) were recruited to participate in an 8-week resistance training program. Prior to participating, all participants were informed of all procedures, risks, and benefits associated with the study and each participant provided his written informed consent. This investigation was approved by the New England Institutional Review Board.

Anthropometric assessments

For all participants, height (±0.1 cm) and body mass (±0.1 kg) were measured using a Health-o-meter professional scale (Model 500 KL, Pelstar, Alsip, IL, USA) with the participants standing barefoot, with feet together, in their normal daily attire. These data were obtained prior to all strength and power measures.

Bar velocity assessment

Average barbell velocity was assessed during 1RM testing of the bench press (BP) and back squat (SQ) exercises using a linear position transducer (Tendo™ Weightlifting Analyzer, Tendo Sports Machines, Trencin, Slovakia) capable of measuring the velocity of concentric bar displacement. The warm-up and testing procedures have been previously described (Hoffman 2006). Briefly, testing occurred during a standard time of day that was consistent with each participant's normal training schedule. Following a standardized general warm-up, a specific warm-up set of 5–10 repetitions was performed using 40–60 % of the participant's perceived 1RM. After a 1-min rest period, a set of 2–3 repetitions was performed at 60–80 % of the participant's perceived 1RM. Subsequently, the 1RM was achieved via 3–5 maximal trials (1-repetition sets) separated by rest periods of 2–3 min. The same absolute loads were used at POST (BP: VOL = 104.5 ± 19.2 kg, INT = 108.8 ± 31.8 kg; SQ: VOL = 140.1 ± 21.6 kg; INT = 145.0 ± 35.4 kg). Prior to the investigation, intraclass correlation coefficient ($ICC_{3,1}$), standard error of the measurement ($SEM_{3,1}$), and minimal difference (MD) values for average bar velocity were measured by the Tendo™ unit during a single repetition of the bench press ($ICC_{3,1} = 0.91$, $SEM_{3,1} = 0.04$ m s^{-1}, MD = 0.09 m s^{-1}) and the squat ($ICC_{3,1} = 0.95$, $SEM_{3,1} = 0.08$ m s^{-1}, MD = 0.15 m s^{-1}) were determined in 10 active, resistance-trained men (26.8 ± 3.5 years; 92.6 ± 6.5 kg; 180.5 ± 6.6 cm) demonstrating that the Tendo™ unit has high test–retest reliability.

Isometric force–time curve assessments

Force production and rate of force development (RFD) were determined for each participant via the isometric mid-thigh pull performed on a portable force plate (AMTI, Watertown, USA). This exercise was selected due to it being more specific (than single-joint exercises) to the resistance training protocols, which predominantly incorporated multi-joint exercises. Participants were instructed to assume a position corresponding to the second pull of a power clean and the height of the bar was adjusted, so that it was level with the mid-point of the thigh. Once proper positioning had been attained, the participants were then instructed to pull upwards on the barbell as hard and as fast as possible until cessation (6 s). After three maximal attempts, each separated by 2–3 min of rest, data were transferred to a personal computer for analysis via

AccuPower (AMTI, Watertown, USA) with a sample rate of 1000 Hz. Peak force (FRC) was defined as the highest force achieved minus the participant's body weight (in Newtons), while force outputs at 30, 50, 90, 100, 150, 200, and 250 ms from the initiation of the pull were also recorded. RFD (N s^{-1}) was calculated using the equation below during the following fixed time intervals: 0–30, 0–50, 0–90, 0–100, 0–150, 0–200, and 0–250 ms. Peak RFD was determined as the highest rate of change in force across a 20-ms sampling window.

$$\mathrm{RFD} = \frac{\Delta \mathrm{Force}}{\Delta \mathrm{Time}}$$

Prior to the investigation, reliability for FRC ($ICC_{2,1} = 0.95$, $SEM_{2,1} = 231$ N, MD = 641 N), FRC at 30 ms ($ICC_{2,1} = 0.80$, $SEM_{2,1} = 84$ N, MD = 233 N), FRC at 50 ms ($ICC_{2,1} = 0.60$, $SEM_{2,1} = 179$ N, MD = 496 N), FRC at 90 ms ($ICC_{2,1} = 0.93$, $SEM_{2,1} = 164$ N, MD = 453 N), FRC at 100 ms ($ICC_{2,1} = 0.91$, $SEM_{2,1} = 147$ N, MD = 406 N), FRC at 150 ms ($ICC_{2,1} = 0.96$, $SEM_{2,1} = 105$ N, MD = 292 N), FRC at 200 ms ($ICC_{2,1} = 0.94$, $SEM_{2,1} = 185$ N, MD = 513 N), FRC at 250 ms ($ICC_{2,1} = 0.93$, $SEM_{2,1} = 267$ N, MD = 741 N), RFD ($ICC_{2,1} = 0.62$, $SEM_{2,1} = 3784$ N s^{-1}, MD = 10489 N s^{-1}), RFD at 30 ms ($ICC_{2,1} = 0.72$, $SEM_{2,1} = 3112$ N s^{-1}, MD = 8626 N s^{-1}), RFD at 50 ms ($ICC_{2,1} = 0.38$, $SEM_{2,1} = 4063$ N s^{-1}, MD = 11,263 N s^{-1}), RFD at 90 ms ($ICC_{2,1} = 0.90$, $SEM_{2,1} = 2005$ N s^{-1}, MD = 5557 N s^{-1}), RFD at 100 ms ($ICC_{2,1} = 0.93$, $SEM_{2,1} = 1623$ N s^{-1}, MD = 4499 N s^{-1}), RFD at 150 ms ($ICC_{2,1} = 0.96$, $SEM_{2,1} = 604$ N s^{-1}, MD = 1674 N s^{-1}), RFD at 200 ms ($ICC_{2,1} = 0.96$, $SEM_{2,1} = 686$ N s^{-1}, MD = 1903 N s^{-1}), and RFD at 250 ms ($ICC_{2,1} = 0.92$, $SEM_{2,1} = 997$ N s^{-1}, MD = 2764 N s^{-1}) was determined in 10 active, resistance-trained men (26.2 ± 3.4 years; 92.3 ± 5.2 kg; 179.8 ± 7.7 cm) using the methodology described above.

Resistance training intervention

Full details of the training programs are described elsewhere (Mangine et al. 2015). Briefly, the preparatory training program and both experimental protocols required the participants to report to the Human Performance Laboratory (HPL) four times per week and consisted of the same exercise sequences performed for four sets. However, the INT training program required the participants to perform 3–5 repetitions with 90 % of their 1RM, with a 3-min rest period between sets, while the VOL group performed sets at 10–12 repetitions with 70 % of their 1RM, with a 1-min rest period between sets. The initial training intensity was determined from 1RM testing (BP and SQ) and estimated 1RM (all other exercises) (Brzycki 1993) from each participant's performance during the preparatory training phase. Progressive overload was achieved by increasing the load when all prescribed repetitions for a particular exercise were achieved on two consecutive workouts. To remain in the investigation, participants were required to complete at least 28 resistance training sessions (~90 %) of the 8-week resistance training program (4 sessions $week^{-1}$).

Statistical analysis

To identify differences between training protocols on changes in isometric force production, RFD, and average bar velocity, an analysis of covariance (ANCOVA) was performed on all measures collected at POST. Associated values collected at PRE were used as the covariate to eliminate the possible influence of initial score variances on training outcomes. In the event of a significant F ratio, a paired-samples t test was used to determine if a significant difference existed between measures collected prior to and immediately following 8 weeks of training.

All between group differences were further analyzed using effect sizes (η^2: Eta squared). Interpretations of effect size were evaluated (Cohen 1988) at the following levels: small effect (0.10), medium effect (0.25), and large effect (>0.40). A criterion alpha level of $p \leq 0.05$ was used to determine statistical significance. All data are reported as mean ± standard deviation. Statistical Software (V. 21.0, SPSS Inc., Chicago, IL, USA) was used for all analyses.

Results

Resistance training program and strength outcomes

Comparisons between groups regarding program adherence, training volume load, training session length, and strength outcomes have been previously reported (Mangine et al. 2015). Briefly, adherence was similar between groups although VOL averaged volume load was ~130 % greater than INT and the VOL group was able to complete their average training session in ~72 % of the time. Improvements in 1RM SQ were similar between groups while improvements in 1RM BP favored INT.

Barbell velocity improvement

Significant ($p < 0.001$) improvements in BP and SQ barbell velocity were observed for both groups with no differences occurring between groups in either BP ($F = 0.012$, $p = 0.915$, $\eta^2 = 0.12$) or SQ ($F = 0.99$, $p = 0.329$, $\eta^2 = 0.24$). Improvements in BP and SQ bar velocity are shown in Fig. 1a, b; respectively.

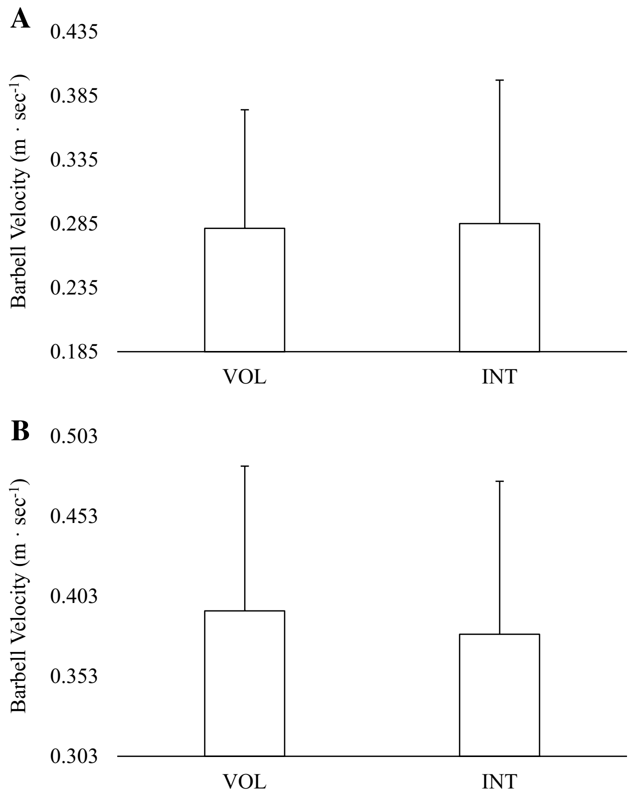

Fig. 1 Changes in bench press and squat barbell velocity. Mean values (±SD) for posttest scores adjusted for initial differences in pretest: **a** bench press barbell velocity (covariate; adjusted pretest mean = 0.185 m s^{-1}); **b** squat barbell velocity (covariate; adjusted pretest mean = 0.303 m s^{-1})

Isometric force–time curve assessments

Significant ($p < 0.05$) differences were observed between groups for changes in peak FRC, FRC output at 30–200 ms, and RFD at 50–90 ms. Significant ($p < 0.05$) improvements in peak FRC and FRC output at 30–200 ms were observed for INT but not for VOL. For changes in RFD, a significant change for INT was observed at 50 ms ($p = 0.040$) only, although a trend was observed at 90 ms ($p = 0.052$). VOL did not experience any significant changes in any of the RFD measures. Group comparisons for changes in peak force production and RFD are presented in Tables 1 and 2, respectively.

Discussion

The results of this study indicate that a high-intensity resistance training program with longer rest periods provides a greater benefit for improving peak isometric force in resistance-trained men. Furthermore, high-intensity resistance training appears to be beneficial in enhancing the RFD during the early contraction phase. However, our hypothesis that higher intensity loads would also provide a greater benefit for enhancing barbell velocity during 1RM testing was not supported in this study.

It was expected that higher training intensity would result in greater force production because of the association of intensity with higher levels of muscle activation (Henneman et al. 1965). Low-threshold type I fibers are initially activated at the onset of the stimulus, and high-threshold type II fibers are progressively recruited based on the size principle. Since recruitment is considered to be a prerequisite for adaptation (Ratamess et al. 2009), the use of heavy loads likely provides an optimal stimulus for maximizing muscle strength. Our data indicate that the loading patterns associated with high-intensity training (and subsequent type II fiber recruitment) may also extend to improvements in RFD (Aagaard et al. 2002). During the early stages of a new training regimen, the primary mechanisms for enhancing strength performance are generally considered to be related to neural adaptations (Moritani 1993; Moritani and deVries 1979). Considering that the participants in the present investigation were experienced lifters (>2 years) and completed the preparation phase prior to initiating the study, it would be reasonable to expect their potential for neurological adaptation to be somewhat limited. Consequently, the observed changes in RFD emphasize the importance of utilizing heavy loads in resistance-trained individuals.

The larger improvements in RFD seen in INT compared to VOL was primarily noted during the early contraction phase (i.e., 50–90 ms), but not during later phases. These findings are in contrast with those previously observed in resistance-trained adults (Marshall et al. 2011). Marshall and colleagues (2011) reported a decrease in RFD, despite improved muscle activation, at 30–50 ms (and peak) following 6 weeks of moderately high-intensity (80 % of 1RM) resistance training performed to fatigue. A possible explanation for those findings and the results of this study may be related to the ability of these training programs to stimulate high-threshold motor units. For instance, previous investigators have demonstrated that changes in early RFD to be positively correlated ($r = 0.61$) to changes in the cross-sectional area percentage of type IIX muscle fibers (Andersen et al. 2010). Despite using similar rest intervals, it is possible that the differences in the exercise protocol (i.e., 80 % of 1RM performed to fatigue) used by Marshall et al. (2011) was not optimal for stimulating adaptation in the high-threshold fibers. In contrast, programming in the present investigation utilized a higher resistance (~90 % of 1RM) and terminated each set following five repetitions. Similar effects on early RFD (0–90 ms) have also been reported in untrained adults exercising with near-maximal (or supramaximal) intensity (Blazevich et al. 2008), as well

Table 1 Changes in peak force production during an isometric mid-thigh pull following 8 weeks of resistance training (mean ± SD)

	PRE	Covariate	POST	F	p value	η^2	95 % confidence interval	
							Lower	Upper
Peak force (N)								
Volume	3256 ± 469	3405	3431 ± 86	11.80	0.002	0.57	3254	3608
Intensity	3544 ± 768		3847 ± 83				3677	4018
Force at 30 ms (N)								
Volume	1118 ± 195	1128	1071 ± 33	10.17	0.004	0.75	1003	1139
Intensity	1137 ± 287		1218 ± 32				1152	1283
Force at 50 ms (N)								
Volume	1272 ± 299	1277	1214 ± 49	9.18	0.005	0.70	1113	1314
Intensity	1281 ± 374		1420 ± 47				1323	1517
Force at 90 ms (N)								
Volume	1517 ± 435	1486	1411 ± 63	7.76	0.010	0.60	1283	1540
Intensity	1457 ± 385		1654 ± 60				1530	1779
Force at 100 ms (N)								
Volume	1554 ± 439	1521	1457 ± 65	6.69	0.016	0.57	1324	1590
Intensity	1489 ± 366		1690 ± 63				1562	1819
Force at 150 ms (N)								
Volume	1792 ± 432	1798	1740 ± 77	4.99	0.034	0.64	1583	1898
Intensity	1803 ± 492		1978 ± 74				1826	2130
Force at 200 ms (N)								
Volume	2094 ± 526	2144	2092 ± 115	4.23	0.050	0.59	1855	2329
Intensity	2190 ± 706		2422 ± 111				2193	2651
Force at 250 ms (N)								
Volume	2204 ± 533	2359	2344 ± 91	1.82	0.189	0.71	2157	2531
Intensity	2504 ± 704		2516 ± 88				2336	2697

as when moderate-to-high intensity loads have been performed explosively (Oliveira et al. 2013a, b). These findings suggest that the ability to stimulate high-threshold muscle fibers during training is an important determinant of RFD adaptation.

The advantages seen in developing force and RFD in the INT group did not translate towards greater benefits in improved barbell velocity during the 1RM assessment. This outcome might be related to how load and fatigue affect repetition velocity. Loads representing a higher intensity of maximal strength typically reduce the velocity in which a repetition can be performed (Hoffman 2014; Ratamess et al. 2009; Zink et al. 2006), whereas high-velocity movements are often recommended for optimal improvements in velocity (Haff and Nimphius 2012; Ratamess et al. 2009). In a similar way, the fatiguing nature of VOL may have also hindered repetition velocity, particularly during later sets and repetitions. It is also possible that the difference in these outcomes is related to testing specificity. Despite strong relationships reported between measures of isometric force production, RFD, and high-velocity movement (i.e., power) (Haff et al. 1997; McGuigan et al. 2010; Nuzzo et al. 2008), a certain degree of precision is lost when comparing measures that possess different biomechanical characteristics. Another possible explanation for these findings may be related to the training status of the participants, whose potential for obtaining improvements may have limited our ability to observe differences within an 8-week study (Hoffman 2014; Ratamess et al. 2009). Thus, it appears that 8 weeks of either high-intensity or high-volume resistance training will produce similar improvements in barbell velocity during dynamic strength testing.

Conclusions

Our study demonstrated that a high-intensity (3-5RM), long rest interval (3 min) resistance training program was more effective than a high-volume protocol with short rest intervals (10–12 RM, 1 min) for stimulating changes in isometric force production and RFD in resistance-trained men. However, the effect of either protocol on barbell velocity during dynamic strength testing appeared to be similar. These results have

Table 2 Changes in rate of force production during an isometric mid-thigh pull following 8 weeks of resistance training (Mean ± SD)

	PRE	Covariate	POST	F	p value	η^2	95 % confidence interval	
							Lower	Upper
Peak RFD (N s^{-1})								
Volume	8880 ± 5251	9054	8263 ± 951	3.36	0.078	0.58	6308	10219
Intensity	9216 ± 5718		10687 ± 919				8798	12577
RFD at 30 ms (N s^{-1})								
Volume	7044 ± 5367	7229	5657 ± 1036	3.98	0.057	0.58	3527	7787
Intensity	7402 ± 6581		8532 ± 1001				6475	10590
RFD at 50 ms (N s^{-1})								
Volume	7325 ± 5125	7318	6262 ± 987	4.43	0.045	0.57	4233	8291
Intensity	7311 ± 5820		9151 ± 954				7191	11111
RFD at 90 ms (N s^{-1})								
Volume	6790 ± 4026	6390	5691 ± 692	4.24	0.050	0.48	4269	7113
Intensity	6016 ± 3464		7677 ± 668				6303	9051
RFD at 100 ms (N s^{-1})								
Volume	6482 ± 3679	6098	5579 ± 643	3.53	0.072	0.44	4257	6902
Intensity	5740 ± 2917		7265 ± 622				5987	8542
RFD at 150 ms (N s^{-1})								
Volume	5904 ± 2618	5911	5599 ± 507	2.78	0.107	0.59	4558	6640
Intensity	5917 ± 3016		6774 ± 489				5768	7779
RFD at 200 ms (N s^{-1})								
Volume	5941 ± 2428	6163	5954 ± 553	3.07	0.091	0.57	4818	7090
Intensity	6371 ± 3337		7303 ± 534				6205	8400
RFD at 250 ms (N s^{-1})								
Volume	5192 ± 1920	5792	5775 ± 359	0.75	0.394	0.67	5038	6512
Intensity	6353 ± 2557		6214 ± 346				5503	6926

important program design implications for resistance-trained individuals looking to improve force and the rate of force production during the early phases of movement.

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