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SKELETAL MUSCLE HYPERTROPHY, MAXIMAL STRENGTH, AND RATE OF FORCE DEVELOPMENT: EFFECTS OF RESISTANCE TRAINING LOADING STRATEGY

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INTRODUCTION: While the benefits of resistance training (RT) are undisputable for enhancing muscle size (Schoenfeld, 2010) and maximal strength (Campos et al., 2002; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Hoffman et al., 2009; Stone et al., 2000), the methods by which coaches prescribe training loads are often debated in research (Painter et al., 2012; Spineti et al., 2013). A variety of RT loading methods are available for coaches to use with their athletes. One popular method of load prescription is the use of repetition maximums (RM). Using RMs necessitate athletes to achieve relative maximums on each day of training for a given set and repetition range (e.g. 3x8 RM). This method is proposed to account for daily perturbations in strength-levels by obtaining true maximums each day in training (Tan, 1999). Conversely, relative intensity (RI) programs typically use percentages based on a previously established or estimated maximum. A variant of RI training prescription uses estimated percentages of set and repetition combinations (e.g. 3x10 or 3x5) to prescribe training loads (RI_{SR}). Currently, there is a paucity of research comparing these two training methods. The purpose of the current study was to compare RI_{SR} to RM programs on measures of muscle fiber hypertrophy, maximal strength, and rate of force development (RFD) in well-trained lifters.

METHODS: Fifteen subjects participated in and completed the study (age = 26.9 ± 3.9 yrs, body mass = 86.2 ± 12.1 kg, BMI = 27.1 ± 3.1, Ht = 1.78 ± 6.5 cm). Subjects were considered well-trained based on their baseline isometric mid-thigh pull peak force (IPF) (4404 ± 665 N) and allometrically scaled isometric peak force (IPFa) (226 ± 26 N/kg$^{0.67}$), which were similar or greater than previously reported values for collegiate athletes (Kawamori et al., 2006; McGuigan & Winchester, 2008; Thomas, Comfort, Chiang, & Jones, 2015). All subjects read and signed an informed consent document prior to participating in the study, as approved by the university's Institutional Review Board.

Both groups followed a block-periodized resistance training program (3 d·wk^{-1} for 10 weeks) consisting of three main phases: strength-endurance, maximum strength, and speed-strength (DeWeese, Hornsby, Stone, & Stone, 2015) . This phase progression, which has been used similarly by other training studies (Harris et al., 2000; Painter et al., 2012), was applied to both training groups simultaneously. However, RI_{SR} training used mostly submaximal intensities (i.e. percentages of set-and-rep maximums), heavy-and-light training days within each week, and down-sets (where appropriate). This ensures that a power-load spectrum (i.e. combination training) takes place weekly. The RM training group used maximal loads within each training session such that each subject would reach muscular failure on the final set of the exercise, indicating a relative maximum had been achieved. If the failed set resulted in repetitions fewer than were prescribed, the load was subsequently reduced by a minimum of 2.5%. However, if the repetitions achieved surpassed the prescription, the load was increased by a minimum of 2.5%. Workloads were monitored for both groups using volume load x displacement (VLd).

Muscle biopsies were sampled at least 72 hours before any study activity and 72 hours after the final training session. Following an overnight fast, a percutaneous needle biopsy of the

VL was obtained using a 5mm Bergstrom-Stille needle under suction (Bergström, 1962; Stuart et al., 2006). The specimen was obtained from the VL at a depth of approximately 3 cm for both pre- and post-testing. The post-sample was taken at a distance 0.5 cm distal of the pre-sample and at the same tissue depth. About half of the 50-100 mg sample was mounted on cork, quickly frozen in isopentane, and cooled in liquid nitrogen for later sectioning on a cryostat (Leica, Wetzlar, Germany) and histochemical analysis. Serial sections were obtained of each sample at a thickness of 14 μm, affixed to a microscope slide, and probed for specific myosin heavy chain (MYH) isoforms: MHY1 for Type IIX fibers (IgM, 1:10 dilution), MYH2 for Type IIA fibers (IgG1, 1:100 dilution), and MYH7 for Type I fibers (IgG2b, 1:200 dilution). Each of these antibodies were obtained from the Developmental Studies Hybridoma Bank (DSHB, University of Iowa, Iowa, USA). Fluorescent images were taken of the stained tissues and were assessed for Type I and Type II fiber cross-sectional area (CSA) using the ImageJ software (National Institute of Health, USA). Isometric mid-thigh pull (IMTP) testing was performed before and after the intervention as previously described (Kraska et al., 2009). Measures of IPF, IPFa, and RFD from 0-50ms (RFD50), from 0-100ms (RFD100), from 0-150ms (RFD150), and from 0-200ms (RFD200) were assessed from IMTP testing.

A 2x5 (group x time) mixed-design analysis of variance (ANOVA) was conducted on each of the dependent variables. Homogeneity of variance using Levene's test and Mauchly's test of sphericity were calculated prior to performing ANOVA tests. Alpha level was set at $p \leq 0.05$. Significant main effects were followed by post-hoc tests using a Holm-Bonferroni adjustment. Statistical analyses were performed on a commercially available statistics software (JASP version 0.8.1.1) and Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA). To assess practical significance, effect size using Hedge's *g* was calculated for pre-post measures. Between-group and within-group effect sizes were calculated using change scores between groups. 90% confidence intervals were calculated for each of these effects. Effect size magnitude was assessed using the following scale: 0.0-0.2 (trivial); 0.2-0.6 (small); 0.6-1.2 (moderate); 1.2-2.0 (large); 2.0-4.0 (very large); 4.0-∞ (nearly perfect) (Hopkins, Marshall, Batterham, & Hanin, 2009).

RESULTS: No statistically significant differences existed between any of the dependent variables at baseline and VLd was not statistically different between groups ($p > 0.05$). ANOVA revealed a statistically significant main effect for time for both Type I and Type II fiber CSA ($p = 0.004$ and $p = 0.003$, respectively). Posthoc analysis revealed statistically significant increases for RI$_{SR}$ only in Type I CSA (p = 0.018) and Type II CSA ($p = 0.012$) with between-group effect size clearly favoring the RI$_{SR}$ group (Type I CSA $g = 0.48$, Type II CSA $g = 0.50$). A statistically significant main effect for time was observed for IPF and IPFa ($p < 0.001$). Upon posthoc analysis, only the RI$_{SR}$ group increased IPF and IPFa significantly ($p < 0.001$). Although both groups increased IPF and IPFa, between-group effect size indicated a superiority for the RI$_{SR}$ group (IPF $g = 0.18$, IPFa $g = 0.20$). A statistically significant interaction effect was observed for RFD50 ($p = 0.02$). The RM group decreased RFD50 significantly ($p = 0.018$) and between-group effect size supported the RI$_{SR}$ group ($g = 1.25$). The same trend was observed for RFD100, as the RM group significantly decreased throughout the intervention ($p = 0.014$) and between-group effect size supported RI$_{SR}$ ($g = 0.89$). No statistically significant effects were observed for either RFD150 or RFD200, however between-group effect size again supported the RI$_{SR}$ group (RFD150 $g = 0.31$, RFD200 $g = 0.13$).

DISCUSSION: The purpose of this investigation was to compare muscle hypertrophy, maximal strength, and RFD alterations between RI_{SR} and RM training strategies. Our results clearly demonstrate a superiority for RI_{SR} training compared to RM, supported by the greater improvements in each of the dependent variables. Muscle fiber hypertrophy was greater in the RI_{SR} group for both Type I and Type II fibers compared to the RM group ($g = 0.48$ and 0.50, respectively). Previous research has described the relationship between training volume and muscle hypertrophy (Schoenfeld, 2010). However, the groups in our study had similar VLd yet yielded different magnitudes of hypertrophy. Training to failure has recently been observed to delay neuromuscular recovery time by up to 48 hours (Moran-Navarro et al., 2017). The consistent training to failure in the RM group may have negatively impacted recovery and the resultant molecularly remodeling of the muscle tissue.

Both groups increased maximal strength, although only RI_{SR} reached statistical significance ($p = 0.018$). Early RFD windows (25-75ms) have been linked to motor unit discharge rates previously (Maffiuletti et al., 2016). Our results showed an impairment in these early RFD windows for the RM group, as RM significantly decreased their RFD from 0-50ms ($p = 0.018$) and 0-100ms ($p = 0.014$). These findings suggest impairment in neural factors as a consequence of RM training. Our results indicate RI_{SR} is a more efficacious training method for well-trained lifters compared to RM training. This is particularly true when considering muscle size and RFD characteristics.

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