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Divergent Performance Outcomes Following Resistance Training Using Repetition Maximums or Relative Intensity

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Purpose: To compare repetition maximum (RM) to relative intensity using sets and repetitions (RI_{SR}) resistance training on measures of training load, vertical jump, and force production in well-trained lifters. ***Methods:*** Fifteen well-trained (isometric peak force = 4403.61 [664.69] N, mean [SD]) males underwent resistance training 3 d/wk for 10 wk in either an RM group (n = 8) or RI_{SR} group (n = 7). Weeks 8 to 10 consisted of a tapering period for both groups. The RM group achieved a relative maximum each day, whereas the RI_{SR} group trained based on percentages. Testing at 5 time points included unweighted (<1 kg) and 20-kg squat jumps, countermovement jumps, and isometric midthigh pulls. Mixed-design analyses of variance and effect size using Hedge's g were used to assess within- and between-groups alterations. ***Results:*** Moderate between-groups effect sizes were observed for all squat-jump and countermovement-jump conditions supporting the RI_{SR} group ($g = 0.76$–1.07). A small between-groups effect size supported RI_{SR} for allometrically scaled isometric peak force ($g = 0.20$). Large and moderate between-groups effect sizes supported RI_{SR} for rate of force development from 0 to 50 ms ($g = 1.25$) and 0 to 100 ms ($g = 0.89$). Weekly volume load displacement was not different between groups ($P > .05$); however, training strain was statistically greater in the RM group ($P < .05$). ***Conclusions:*** Overall, this study demonstrated that RI_{SR} training yielded greater improvements in vertical jump, rate of force development, and maximal strength compared with RM training, which may be explained partly by differences in the imposed training stress and the use of failure/nonfailure training in a well-trained population.

Keywords: maximal strength, periodization, rate of force development, vertical jump

Resistance training (RT) has repeatedly shown the capability to enhance physical performance characteristics, such as maximal strength[1–4] and rate of force development (RFD).[5] Maximal strength and RFD are critically important for athletes, particularly in strength–power sports.[6,7] Although RT has been shown to enhance these and other physical traits, exercise or training intensity seems to play a major role in facilitating these improvements.[8] Both high-load/high-force and low-load/high-velocity loading prescriptions have been shown to enhance jump performance.[9,10] However, a combination of high-force and high-velocity training may provide superior results.[1,9–12] Toji and Kaneko[12] observed greater peak power output increases (52.9%) in the elbow flexors when varying heavy and light training loads (ie, greater load ranges throughout study). Similarly, Cormie et al[10] showed that the combination of "optimally" loaded jump squats with heavy squats was superior to only jump squat training in producing increases in peak jump power and height. These observations indicate that a broad range of loading is necessary for superior improvements in ballistic movements. Therefore, loading strategies should be carefully considered when designing RT programs for athletes requiring high rates of force development.

There are a number of prevalent strategies for load prescription in RT. Two popular strategies include using a percentage of a 1-repetition maximum (%1RM)[1,2,13,14] or repetition maximum (RM) zones.[4,15] Proponents of RM zone training suggest it is superior to %1RM due to acute fluctuations in daily strength levels.[15] Therefore, by completing RMs in training, it has been suggested that practitioners can account for these perturbations in strength levels and more accurately prescribe training loads.[15] Conversely to RM zones, training programs based on %1RM (often referred to as relative intensity, RI) use mostly submaximal training intensities or percentages.[8,15] RI loading is a popular method for prescribing a more undulated training approach using heavy and light training days within each training week.[16,17] Furthermore, due to fluctuations in 1RM values (eg, due to daily fatigue levels), a variant of RI loading has been developed (RI_{SR}) using percentages of set and repetition combination maximums instead of %1RM to prescribe training loads.[16] Using the RI_{SR} strategy, each set and repetition combination (eg, 3 × 10 vs 3 × 5) has a specific 100% value, as opposed to constantly being related back to a 1RM. Proponents of RI_{SR} suggest that using submaximal training intensities and heavy and light training days results in better fatigue management and superior adaptations compared with RM training.[1,3,16,18]

Differences in physiological and performance changes between these 2 RT load prescription strategies have not been compared. Therefore, the purpose of our investigation was to compare RM to RI_{SR} training on measures of training load, vertical jump, and maximal strength in well-trained lifters. We hypothesized that the greater variations in training intensity and attention to fatigue management in RI_{SR} would result in superior performance changes compared with RM training.

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Methods

Subjects

Fifteen well-trained males volunteered to participate in the study (age = 26.94 [3.95] y, body mass = 86.21 [12.07] kg, and body mass index = 27.07 [3.08] kg/m^2). All subjects were required to have at least 1 year of RT experience at a minimum frequency of 3 days per week. Experience was confirmed based on a questionnaire and careful questioning by the investigators. Subjects were considered well-trained based on their baseline isometric midthigh pull peak force (IPF; 4403.61 [664.69] N) and allometrically scaled isometric peak force (IPFa; 226.04 [25.81] N/kg$^{0.67}$), which were similar to or greater than previously reported values for collegiate athletes.[19–21] Subjects were ranked based on initial IPFa, and matched pairs were randomly assigned into either a RI$_{SR}$ group (n = 7) or an RM zone group (n = 8). All subjects read and signed an informed consent document prior to participating in the study, as approved by the East Tennessee State University Institutional Review Board.

Training Programs

Following baseline testing, subjects completed RT 3 days per week for 10 weeks (Table 1). RT was completed on Mondays, Wednesdays, and Fridays (Table 2), whereas a rudimentary sprint program was completed on Tuesdays and Thursdays. The sprint program consisted of 2 to 3 sets of three 20-m sprints with 2 minutes of rest between repetitions and 4 minutes of rest between sets for both groups. The purpose of the sprint program was to provide a stimulus more like what a typical strength–power athlete would encounter. Where most RT studies only provide a stimulus on RT days, we attempted to more closely mimic training that occurs in the real world. Subjects in the study completed 100% of the training sessions. All training sessions were supervised by trained and certified strength and conditioning coaches (subject-to-coach ratio ranging from 1:7 to 1:8). Strength coaches were rotated periodically to reduce potential coaching bias. Both groups performed the same dynamic warm-up preceding each training session. The warm-up consisted of general calisthenics, multidirectional lunge movements, leg swings, squatting patterns, and build-up sprints. Additionally, subjects were encouraged to give maximal effort for all repetitions throughout each training session. All subjects trained within the same 3-hour window each day. Work was estimated by volume load displacement from all warm-up and working sets (VLd = sets × repetitions × vertical displacement)[18] and session rating of perceived exertion (sRPE).[22] Vertical displacement was measured using a linear position transducer (OpenBarbell, Brooklyn, NY). To further interpret the workloads experienced during each group's RT, training monotony (TM) and training strain (TS) were calculated for each week using sRPE multiplied by session duration. TM was calculated by dividing the mean weekly sRPE by the SD of the week, and TS was calculated as the product of the mean weekly sRPE and the TM score for the week.[23,24]

Both groups followed a block-periodized program consisting of 3 main phases: strength endurance, maximum strength, and speed strength.[18] This phase progression, which has been used similarly by other training studies,[1,17] was applied to both training groups. The final 2 weeks of the intervention for both groups consisted of a tapering period. This taper immediately followed a functional overreach. For both groups, the tapering period included a reduced volume of training and also incorporated complex training where the main movements were combined with plyometric-type exercises. However, RI$_{SR}$ training used mostly submaximal intensities (ie, percentages of set and repetitions maximums), heavy and light training days within each week, and downsets (where appropriate). The maximums for each set

Table 1 Resistance Training Programs

			RI$_{SR}$		
Training block	Week	Sets × repetitions	Day 1 and Day 2	Day 3	RM zone
(A) VJ and IMTP testing					
Strength endurance	1	3 × 10	80.0%	70.0%	3 × 8–12
	2	3 × 10	85.0%	75.0%	3 × 8–12
	3	3 × 10	90.0%	80.0%	3 × 8–12
(B) VJ and IMTP testing					
Maximum strength[a]	4	3 × 5	85.0%	70.0%	3 × 4–6
	5	3 × 5	87.5%	72.5%	3 × 4–6
	6	3 × 5	92.5%	75.0%	3 × 4–6
	7	3 × 5	80.0%	65.0%	3 × 4–6
(C) VJ and IMTP testing					
Overreach	8	5 × 5	85.0%	75.0%	5 × 4–6
(D) VJ and IMTP testing					
Speed strength	9	3 × 3	87.5%	67.5%	3 × 2–4
	10	3 × 2	85.0%	65.0%	3 × 1–3
(E) VJ and IMTP testing					

Abbreviations: IMTP, isometric midthigh pull; RI$_{SR}$, relative intensity based on sets and repetitions; RM, repetition maximum; VJ, vertical jump.

[a] Symbolizes downset at 60% of working weight (RI$_{SR}$ only).

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Table 2 Training Exercises for All Subjects

Training block	Day 1	Day 2	Day 3
Strength endurance	Back squat, overhead press, bench press, DB triceps extension	CG MTP, CG SLDL, BB bent row, DB bent lateral raise	Back squat, overhead press, bench press, DB triceps extension
Maximum strength	Back squat, push press, incline bench press, weighted dips	CG MTP, clean pull, SG SLDL, pull-ups	Back squat, push press, incline bench press, weighted dips
Overreach	Back squat, push press, DB step up, bench press	CG CM shrug, clean pull, CG SLDL, SA DB bent row	Back squat, push press, DB step up, bench press
Speed strength	Back squat + rocket jump, push press, bench press + medicine-ball chest pass	CG MTP, CG CM shrug, vertical medicine-ball toss	Back squat + rocket jump, push press, bench press + medicine-ball chest pass

Abbreviations: BB, barbell; CG, clean group; CM, countermovement; DB, dumbbell; MTP, midthigh pull; SA, single arm; SG, snatch grip; SLDL, stiff-legged deadlift.

and repetition combination were as follows: 100% was very heavy, 90% to 95% was heavy, 85% to 90% was moderately heavy, 80% to 85% was moderate, 75% to 80% was moderately light, 70% to 75% was light, and 65% to 70% was very light.[16,25] Heavy and light training days consisted of a specific intensity reduction from day 1 to day 3 in the RI_{SR} group: 10% for strength endurance and overreach, 15% for maximum strength, and 20% for speed strength (Table 1). Loads were adjusted weekly based on estimated set–repetitions bests within each set–repetitions combination (3 × 10, 3 × 5, 5 × 5, 3 × 3, and 3 × 2).[16,26]

Unlike RI_{SR} training, the RM training group used maximal loads within each training session and RM zone prescription (3 × 8–12, 3 × 4–6, 5 × 4–6, 3 × 2–4, and 3 × 1–3). The goal of the RM zone prescription was that each subject would reach muscular failure on the final set of the exercise, indicating that a maximum had been achieved. If the failed set resulted in fewer repetitions 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%. All other factors not pertaining to the loading strategy (ie, training times, rest intervals, training volumes) were controlled between groups to the best of our ability. Rest periods between RT sets were 3 to 5 minutes for both groups. Throughout the intervention, subjects were instructed to refrain from excessive physical activity outside of training and on rest days. Subjects were also instructed to maintain their typical dietary habits throughout the intervention and to abstain from taking stimulants prior to any testing or training sessions.

Vertical Jump Assessments

Squat jumps (SJs) and countermovement jumps (CMJs) were assessed at 5 time points as indicated in Table 1 using unweighted (<1 kg) and weighted (20 kg) conditions. Jump height (JH) and allometrically scaled peak power (PPa) were measured during each jump condition. All performance testing was completed 72 hours following the most recent training stimulus. Baseline testing was considered time point A, and all other time points were, in order, B, C, D, and E (where E is the posttest). Following a standardized dynamic warm-up,[27] each subject performed 2 warm-up SJs with a plastic pipe (<1 kg) rested on the trapezius muscles just below the seventh cervical vertebrae. The plastic pipe was used to eliminate arm swing and to standardize testing conditions between subjects. SJs were performed from an internal knee angle of 90° measured using a goniometer. Following 50% and 75% effort warm-up jumps, 2 maximal effort SJs were performed on dual-force plates (2 × 91 cm × 45.5 cm) sampling at 1000 Hz (Rice Lake Weighing Systems, Rice Lake, WI). Following the SJs, CMJ testing was performed using identical procedures. Data were collected and processed using a LabView program (LabView 8.6, and 2010; National Instruments Co, Austin, TX). Sixty seconds of rest were given between each jump trial and between jump types. JH was estimated from flight time as described previously.[28] The force-time trace was converted to an acceleration-time trace, which was then differentiated to obtain a velocity-time trace. Peak power was the maximal value obtained from the product of the velocity-time and force-time trace, and was allometrically scaled to account for differences in body mass. The mean of the 2 best trials within a 2-cm difference in JH was used for analysis. Additional trials were performed when the difference between 2 trials was greater than 2 cm. Reliability was assessed by intraclass correlation coefficients (ICCs) and coefficient of variation (CV) for JH (ICC = .99, CV = 1.96%) and PPa (ICC = .92, CV = 2.24%).

Isometric Midthigh Pull Assessments

Isometric peak force, IPFa, and RFD were assessed from isometric midthigh pulls (IMTP) performed at each testing time point. Specifically, RFDs from 0 to 50 ms (RFD50), from 0 to 100 ms (RFD100), from 0 to 150 ms (RFD150), and from 0 to 200 ms (RFD200) were considered. Following a standardized warm-up,[27] each subject was positioned in a custom-built power rack with an affixed bar. Subject internal knee and hip angles were measured manually using a goniometer and were required to be 130° (5°) and 150° (5°), respectively. Each power rack contained dual-force plates (2 × 91 cm × 45.5 cm) sampling at 1000 Hz (Rice Lake Weighing Systems). Subjects were secured to the bar using straps and athletic tape to eliminate grip strength as a confounding variable during testing. Prior to maximal effort trials, a 50% and a 75% warm-up effort was completed, separated by 60 seconds of rest. Three minutes of rest was given following the final warm-up effort. Each subject completed 2 maximal effort IMTP trials and was instructed to "pull as fast and as hard" as he or she could. Additional trials were completed if the IPF differed between trials >250 N or if there was a >200 N countermovement in any trial. Verbal encouragement was provided during every IMTP effort. Three minutes of rest were given between trials. Kinetic data were processed using commercially available software (ForceDecks; NMP Technologies Ltd, London, United Kingdom). Within-subject, between-trial reliability assessed by ICC, and within-subject CV, were as follows: IPF (ICC = .95, CV = 2.83%), IPFa (ICC = .95, CV = 2.83%), RFD50 (ICC = .74, CV = 24.16%), RFD100 (ICC = .81, CV = 21.24%), RFD150 (ICC = .83, CV = 16.55%), and RFD200 (ICC = .83, CV = 12.01%). The 2 IMTP trials were averaged together for statistical analysis.

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Statistical Analysis

After verifying that there were no between-group differences for SJ, CMJ, and IMTP ($P > .05$) at baseline, a 2 × 5 (group × time) mixed-design analysis of variance was conducted. Additionally, VLd, TM, and TS were compared using a 2 × 10 (group × time) mixed analysis of variance. Homogeneity of variance using Levene's test and Mauchly's test of sphericity were calculated prior to performing analysis of variance tests. The alpha level was set at $P \leq .05$. Significant main effects were followed by post hoc tests using a Holm–Bonferroni adjustment. Specific interest was given to post hoc tests between the A and E (pre to post) time points and the D to E (before and after the taper) time points. These points of interest were chosen due to the importance of both (1) the changes from baseline to post study and (2) the changes associated with a taper period, which has been shown to be an important aspect of training.[29–31] Statistical analyses were performed on a commercially available statistics software (JASP version 0.8.1.1) and Microsoft Excel 2016 (Microsoft Corp, Redmond, WA). To assess practical significance, the effect size using Hedge's *g* was calculated for pre–post measures.[32] Within-group effect sizes were calculated using pre and post mean and SD values for each group. Between-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 to 0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; 2.0 to 4.0, very large; 4.0 to ∞, nearly perfect.[33]

Results

Analysis of variance revealed a statistically significant interaction effect for VLd ($P < .001$), and TS ($P = .005$); a significant main effect for time was observed for TM ($P = .033$). Further analysis revealed simple time effects for VLd ($P < .001$) and TS ($P < .001$) in both groups. Post hoc testing revealed statistically greater TS for the RM group in weeks 3 to 10, but not for VLd or TM (Figures 1 and 2). Body mass and body mass index resulted in statistically significant main effects for time ($P < .001$).

Unweighted squat-jump height (SJH) yielded a statistically significant main effect for time ($P = .006$). Post hoc analysis revealed statistically significant increases for the RI_{SR} group from A to E ($P = .009$) and from D to E ($P = .023$), but not for the RM group ($P > .05$) (Figure 3). A significant interaction ($P = .046$) was observed for SJH with 20 kg. Simple main time effects were observed for RI_{SR} ($P = .021$) and for RM ($P = .036$). The RI_{SR} group improved significantly in SJH 20 kg from A to E ($P = .012$) and from D to E ($P = .014$), whereas the RM group only improved from D to E ($P = .003$). Significant interaction effects occurred for both countermovement-jump height (CMJH) conditions ($P = .006$ and $P < .001$, respectively). Simple main effects for time were significant only for RM CMJH 20 kg ($P = .001$). Post hoc comparisons revealed no statistically significant differences between groups at any time point for unweighted CMJH ($P > .05$), whereas for CMJH at 20 kg a difference was observed at time point D ($P = .033$) (Figure 4). Additionally, the RM group significantly improved CMJH 20 kg only between D and E ($P = .031$). Between-group effect magnitudes supported the RI_{SR} group for all measures of JH with moderate effects ($g = 0.76–1.07$; Table 3).

Allometrically scaled peak power revealed statistical main effects for time at unweighted SJ and 20-kg SJ conditions ($P < .001$ and $P = .02$, respectively). The RI_{SR} group statistically increased unweighted SJ PPa from A to E ($P = .003$) and from D to E ($P = .026$), whereas no statistical change was present for RM ($P > .05$). The RI_{SR} group also statistically increased 20-kg SJ PPa from A to E ($P = .024$). A significant interaction effect ($P = .024$) was observed for 20-kg CMJ PPa, with post hoc tests revealing a significant between-group difference at the D time point ($P = .045$). For all scaled peak power measures, both within- and between-group effect magnitudes supported the RI_{SR} group (Table 3).

Statistically significant main effects for time were observed for IPF and IPFa ($P < .001$). Statistically significant increases in

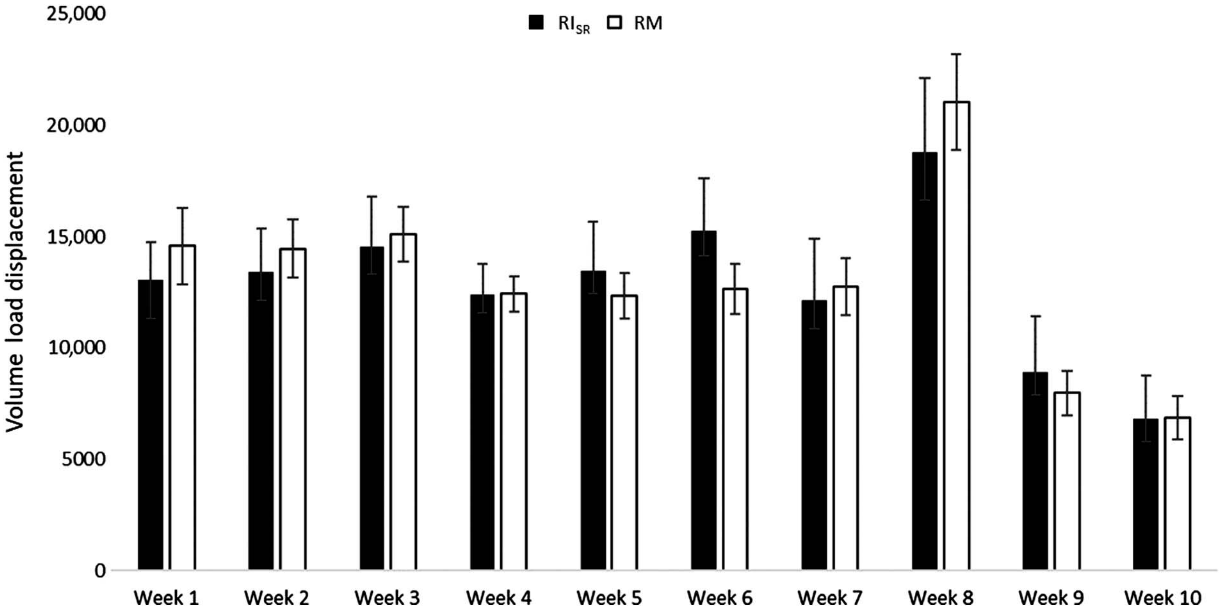

Figure 1 — Weekly volume load displacements for RI_{SR} and RM groups were similar for all weeks ($P > .05$). RI_{SR} indicates relative intensity based on sets and repetitions; RM, repetition maximum.

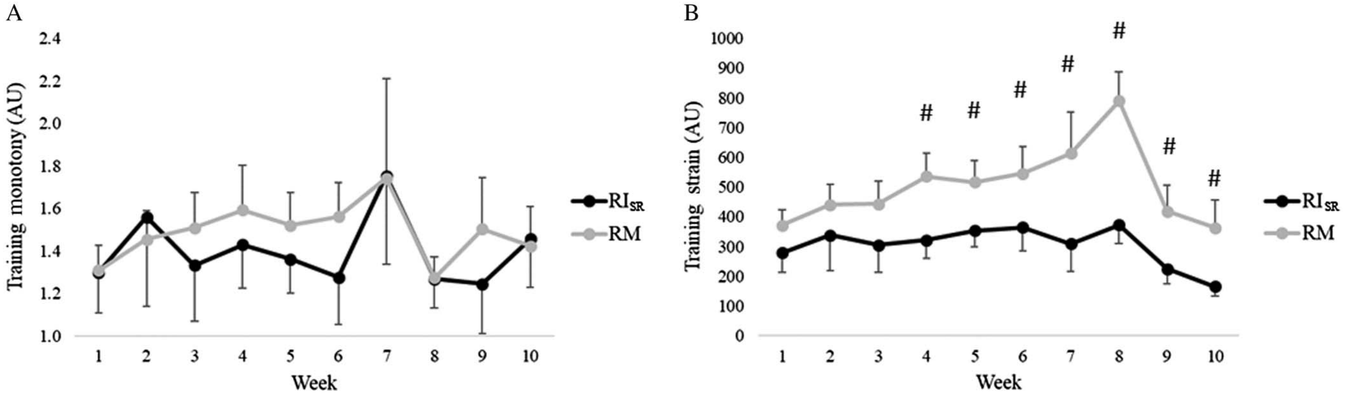

Figure 2 — (A) Training monotony and (B) training strain were statistically higher for RM at week 3. These measures were also higher than RI for all other weeks, although without statistical significance. RI$_{SR}$ indicates relative intensity based on sets and repetitions; RM, repetition maximum. #Between-groups difference at specific time point.

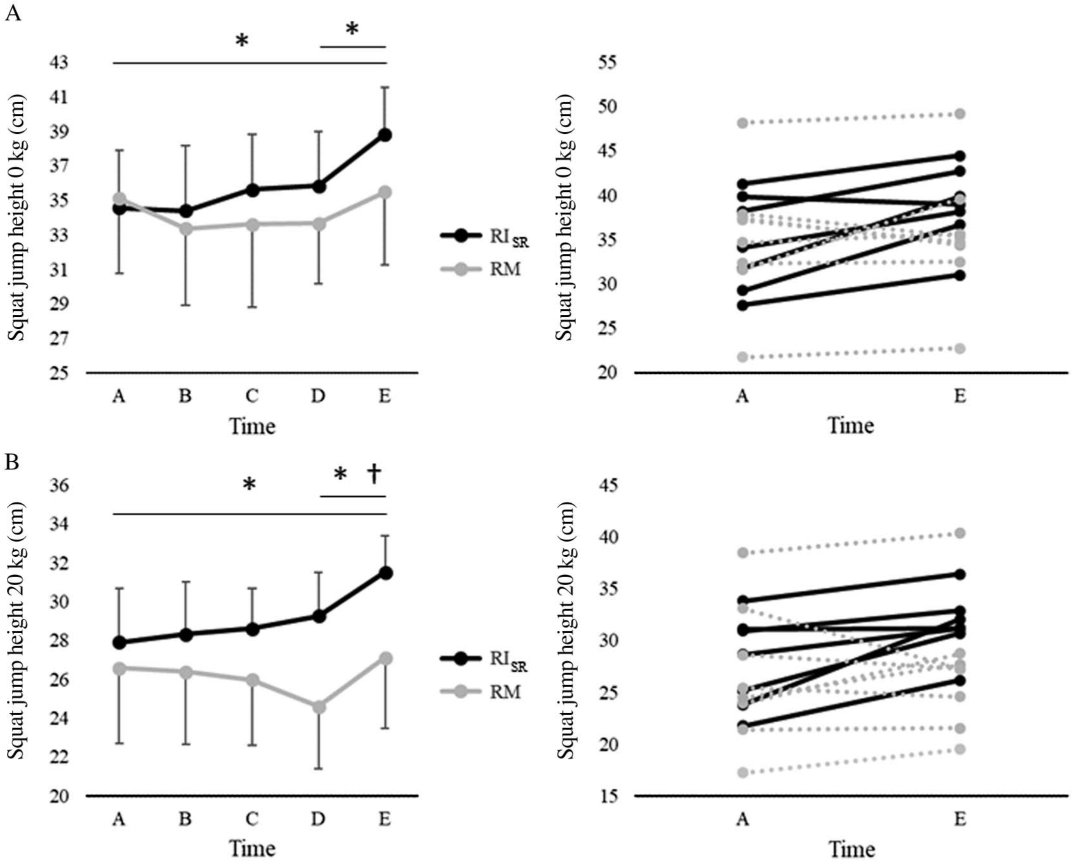

Figure 3 — Alterations in squat-jump height for both (A) unweighted and (B) 20-kg conditions. RI resulted in statistically significant increases in squat-jump height from A to E and D to E, whereas RM increased squat-jump height significantly only from D to E. Individual data are represented to the right of the group data. RI$_{SR}$ indicates relative intensity based on sets and repetitions; RM, repetition maximum. *Statistically significant change for RI group only. †Statistically significant change for RM group only.

IPF and IPFa were observed from A to E for the RI$_{SR}$ group only ($P < .001$). A statistically significant interaction ($P = .049$) was observed for RFD50. A statistically significant decrease in RFD50 from A to E was observed for the RM group only ($P = .018$), with no other statistical changes for either group ($P > .05$) (Figure 5). A statistically significant time main effect was observed for RFD100 ($P = .014$). A statistically significant decrease in RFD100 from A to E was observed in the RM group only ($P = .014$). Both within- and between-group effect magnitudes supported the RI$_{SR}$ group for all IMTP variables.

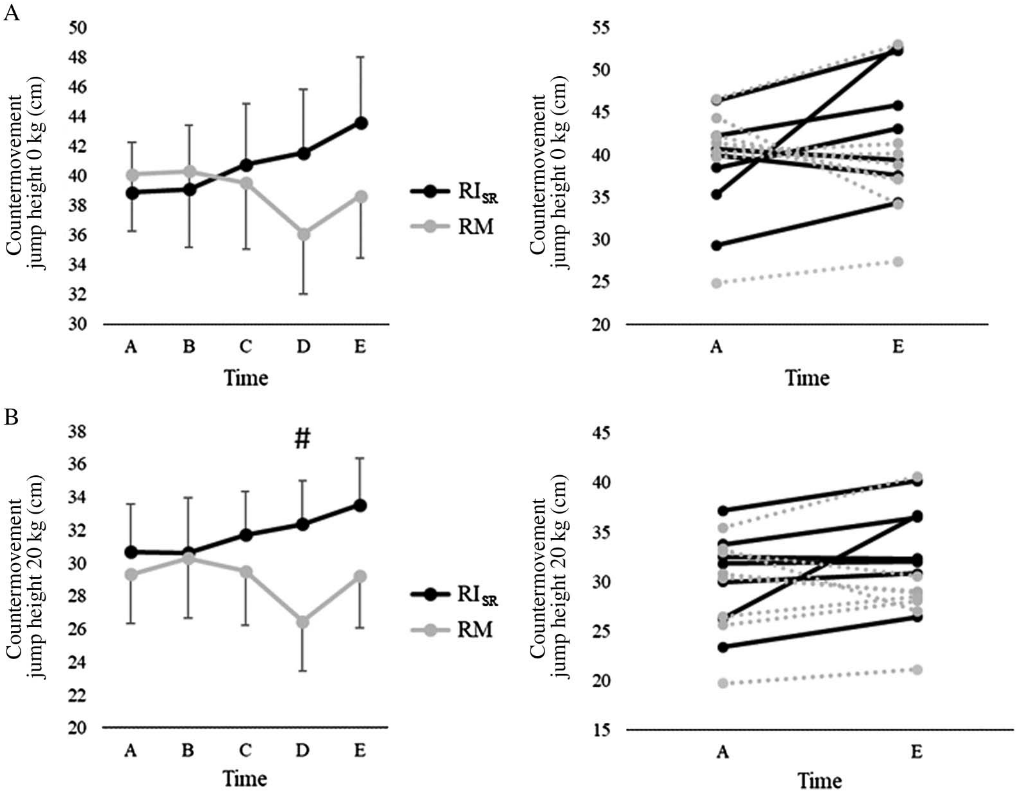

Figure 4 — Alterations in countermovement-jump height for both (A) unweighted and (B) 20-kg conditions. No within-group differences existed for countermovement-jump variables, but there was a statistically significant between-groups difference for 20-kg countermovement-jump height at time point D. Individual data are represented to the right of the group data. RI$_{SR}$ indicates relative intensity based on sets and repetitions; RM, repetition maximum. #Between-groups difference at specific time point.

Table 3 Effect Size Using Hedge's *g* and 90% CIs for Within-Group and Between-Groups Effects

	Relative-intensity effects			Repetition-maximum effects			Between-groups effects
Variable	***g* (±CI)**	**Pre (SD)**	**Post (SD)**	***g* (±CI)**	**Pre (SD)**	**Post (SD)**	***g* (±CI)**
SJ 0-kg JH	0.82 (±0.42)	0.35 (0.05)	0.39 (0.04)	0.05 (±0.30)	0.35 (0.07)	0.35 (0.07)	1.07 (±0.83)
SJ 20-kg JH	0.89 (±0.49)	0.28 (0.04)	0.32 (0.03)	0.08 (±0.32)	0.27 (0.07)	0.27 (0.06)	0.91 (±0.83)
CMJ 0-kg JH	0.69 (±0.70)	0.39 (0.05)	0.44 (0.07)	−0.2 (±0.47)	0.40 (0.07)	0.39 (0.07)	0.97 (±0.84)
CMJ 20-kg JH	0.58 (±0.54)	0.31 (0.05)	0.34 (0.05)	−0.02 (±0.43)	0.29 (0.05)	0.29 (0.05)	0.76 (±0.83)
SJ 0-kg PPa	0.96 (±0.39)	246 (25)	270 (20)	0.21 (±0.26)	229 (45)	239 (42)	0.81 (±0.82)
SJ 20-kg PPa	0.71 (±0.46)	246 (29)	265 (20)	0.14 (±0.29)	224 (45)	230 (40)	0.64 (±0.83)
CMJ 0-kg PPa	0.29 (±0.63)	258 (27)	266 (27)	−0.01 (±0.35)	240 (35)	240 (42)	0.35 (±0.84)
CMJ 20-kg PPa	0.20 (±0.48)	254 (30)	260 (22)	0.08 (±0.33)	231 (35)	234 (35)	0.15 (±0.83)
IPF	1.05 (±0.23)	4382 (648)	5161 (733)	0.83 (±0.67)	4500 (621)	5159 (864)	0.18 (±0.81)
IPFa	1.26 (±0.26)	219 (26)	254 (24)	0.98 (±0.86)	235 (18)	263 (33)	0.20 (±0.81)
RFD50	0.37 (±0.72)	3646 (2034)	4613 (2768)	−0.94 (±0.58)	5534 (2060)	3466 (2118)	1.25 (±0.84)
RFD100	0.12 (±0.68)	7778 (4061)	8374 (5068)	−0.61 (±0.36)	10,577 (4754)	7682 (4274)	0.89 (±0.84)
RFD150	−0.02 (±0.62)	8925 (3728)	8821 (4580)	−0.34 (±0.39)	9982 (2865)	8743 (3922)	0.31 (±0.84)
RFD200	0.01 (±0.06)	8364 (2623)	8398 (3475)	−0.19 (±0.94)	8813 (1681)	8307 (3058)	0.13 (±0.82)

Abbreviations: 90% CI, 90% confidence interval; CMJ, countermovement jump; *g*, Hedge's *g* effect size; IPF, isometric peak force; IPFa, allometrically scaled isometric peak force; JH, jump height; PPa, allometrically scaled peak power; RFD, rate of force development; SJ, squat jump.

Discussion

The purpose of our investigation was to compare RM to RI$_{SR}$ training on measures of training load, vertical jump, and maximal strength in well-trained lifters. The main findings of the study were as follows: (1) In support of our hypothesis, the RI$_{SR}$ training group achieved superior improvements in vertical JH and peak power outputs compared with the RM group throughout the intervention. (2) Although both groups improved maximal strength, as measured by IPF and IPFa, only the RI$_{SR}$ group reached statistical

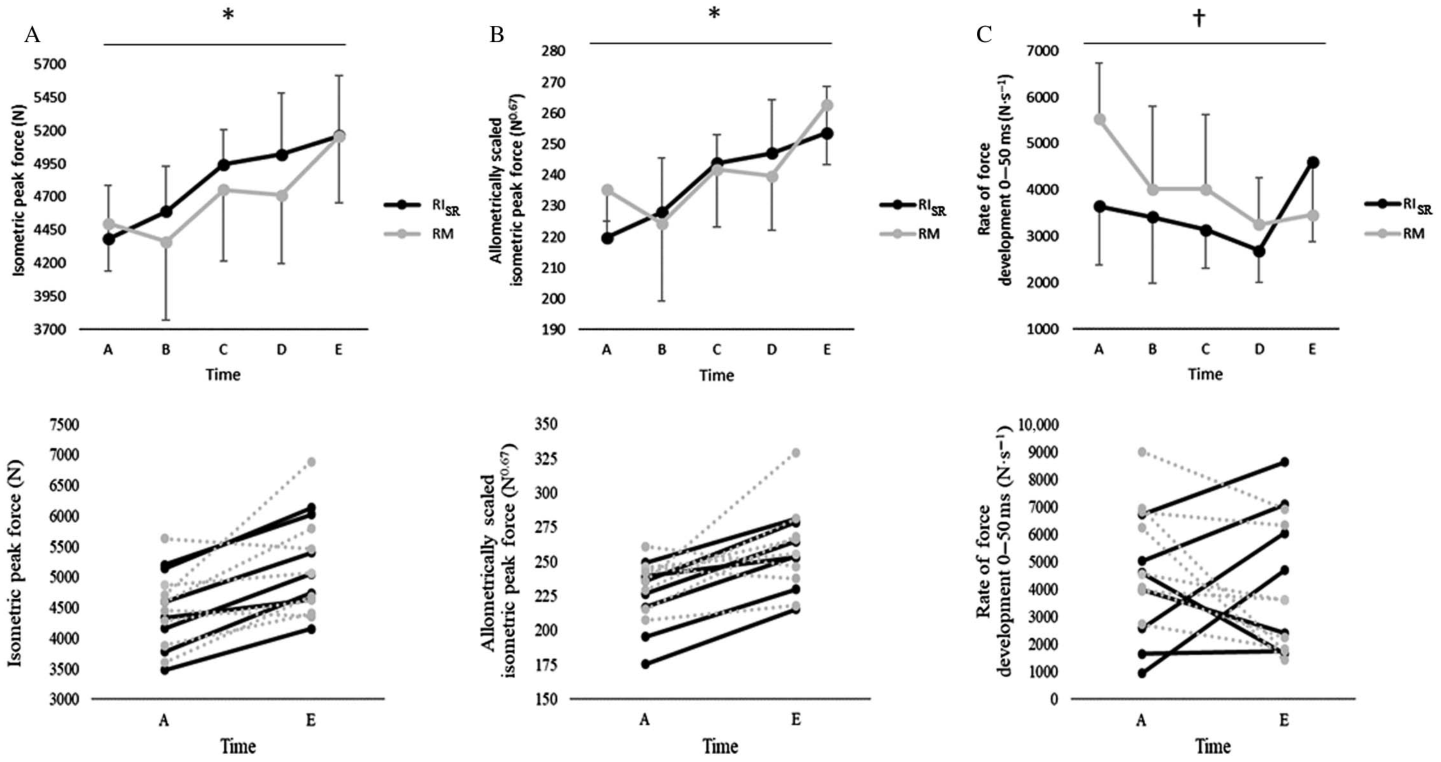

Figure 5 — RI resulted in statistically significant increases from A to E for (A) isometric peak force and (B) allometrically scaled isometric peak force. RM resulted in a statistically significant decrease in (C) rate of force development from 0 to 50 ms. Individual data are represented below the group data. RI_{SR} indicates relative intensity based on sets and repetitions; RM, repetition maximum. *Statistically significant change for RI group only. †Statistically significant change for RM group only.

significance and showed larger effect sizes. Interestingly, the RM group statistically decreased RFD50 throughout the intervention. (3) Work, estimated as VLd, was similar throughout the intervention with the exception of a single day. (4) TS was consistently greater for RM compared with RI_{SR}. Further inspection of the within- and between-group effect magnitudes (Table 3) revealed virtually all performance variables within the current study supported the RI_{SR} group. Our findings suggest that RI_{SR} training may be advantageous compared with training with RM zones for athletes who aim to improve jumping performance and force production capabilities.

Although the work completed by each group was similar across the intervention (Figure 1), the imposed stress demands differed. For example, the TS was significantly greater in the RM group compared with the RI_{SR} group throughout the majority of the intervention (Figure 2). As TS is a measure of the total stress imposed on an individual,[23] this demonstrates that the RM group was exposed to high levels of training stress even given the similar external workloads (VLd). By contrast, the RI_{SR} group had comparatively low TS scores, most likely as a function of heavy and light training days during each week. The greater TS observed in the RM group likely contributed to their inability to increase performance to the degree of the RI_{SR} group. This concept is not new, as high levels of monotony and strain have been suggested to impair adaptation and may potentially contribute to poor fatigue management and overtraining.[23,] These findings demonstrate that differences in imposed training stress between training programs can impact performance outcomes despite similarities in total work completed.

Greater SJH and SJ PPa improvements were observed in the RI_{SR} group compared with the RM group. A possible mechanism may point to enhanced type II muscle fiber content and cross-sectional area in the RI_{SR} group, as positive relationships have been observed previously between SJ performance and type II fiber content and size.[34,35] CMJ performances were also superior in the RI_{SR} group from pre to post, suggesting favorable enhancements in stretch-shortening cycle function. In contrast, the decreases in CMJH in both loads for the RM group indicate an impaired stretch-shortening cycle function, likely resulting from the residual fatigue of repeated training to failure. In support of this, Moran-Navarro et al[36] recently demonstrated that performing bench press and back squats to failure delays recovery of CMJ performance by up to 24 to 48 hours postexercise.[36] Therefore, RI_{SR} training may stimulate greater CMJ performance improvements than RM training by permitting shorter recovery times between training sessions.

Both maximal strength and RFD can be impacted by fatigue.[37] Previous research has shown increases in maximal strength following RM training.[4,38] This is supported by our results, as both groups increased IPF and IPFa (RI_{SR}: $g = 1.05–1.26$, RM: $g = 0.83–0.98$), whereas only the RI_{SR} group reached a statistically significant increase ($P < .001$). RFD seems to have greater sensitivity to fatigue compared with maximal strength,[39] possibly due to neural factors. Indeed, early RFD measures (25–75 ms) have been linked to motor unit discharge rates.[7] The statistically significant reductions in early RFD observed in the RM group (RFD50: $P = .018$, RFD100: $P = .014$) seem to suggest impaired neural drive. These findings may have major implications for athletes,

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as RFD is critically important for performing time-sensitive tasks in sport.[5,7] Therefore, RM training may result in inferior training adaptations to RI_{SR} training, particularly as it relates to rapid force production.

A taper was prescribed for both groups between time points D and E. The taper consisted of reduced volume, relatively high intensity, and more explosive exercises (eg, downsets of ballistic medicine ball throws for both groups).[29,40,41] An interesting observation was a noticeable increase in performance following the taper, regardless of group. These data are particularly intriguing as the "D" and "E" time points were separated by only 2 weeks. This agrees with a recent recommendation that tapers to improve maximal strength should last from 1 to 4 weeks.[41] Although RM training also benefited from a taper, this does not obviate the inferior performance adaptations observed throughout the intervention. Even with a taper, the RM group was unable to return to their baseline values for several variables (CMJH and early RFD). These findings demonstrate an impaired ability to fully recover in the RM group despite reduced training, which is indicative of nonfunctional overreaching.[42] Furthermore, these depressed performance variables observed in the RM group provide further support for RI_{SR} as an efficacious training strategy. However, these data suggest regardless of training strategy, a taper should be used when optimal performances are the goal.

Practical Applications

This investigation revealed potentially deleterious effects of RT to failure in well-trained populations. Compared with the relative simplicity of training to failure to adjust training loads, using more complex methods of load adjustment (ie, RI_{SR}) may provide additional benefits in the form of improved fatigue management and optimal performance adaptations. Coaches and athletes should consider managing training loads in a similar fashion to how the RI_{SR} group trained, allowing athletes to train further away from their maximums and vary intensities when necessary. It should be noted that there was relatively high between-subject variability in RFD measures (Table 3). Readers should consider the variable nature of RFD measurements when interpreting these performance results. Sample size was limited due primarily to other, more invasive tests performed on this same cohort (ie, muscle biopsies). We recognize the limitations associated with small sample sizes, and this should be considered when interpreting the results of the study. However, in a well-trained subject pool, the sample size seemed adequate.

Conclusions

Overall, this study demonstrated that RI_{SR} training resulted in consistently greater improvements in vertical jump and force production capabilities compared with RM training, which may be explained partly by the differences in the imposed stress and design of RT workloads between groups. Furthermore, the similar workloads but drastically different TS experienced between groups highlight the importance of tactics within the training process. Although RM training resulted in an increase in maximal strength, the obvious impairments to vertical jump and early RFD performance bring into question the efficacy of training to failure in populations where optimal performance enhancement is the goal, such as in competitive athletes. Practitioners should consider the use of RI_{SR} training with the inclusion of adequately varied training stimuli, such as heavy and light training days and a variety of high-force and high-velocity outputs.

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