Efficacy of Rest Redistribution During Squats: Considerations for Strength and Sex

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Abstract

Boffey, D, Clark, NW, and Fukuda, DH. Efficacy of rest redistribution during squats: Considerations for strength and sex. *J Strength Cond Res* 35(3): 586–595, 2021—This study examined the kinematic, perceptual, and heart rate responses to rest redistribution (RR) and traditional sets (TS) during the barbell back squat for men and women possessing a wide range of strength levels. Forty-five resistance-trained subjects (30 men and 15 women) performed 40 repetitions of the barbell squat with 65% 1RM load with TS (4 × 10 repetitions, 3-minute rest) or RR (10 × 4 repetitions, 1-minute rest), in a randomized order on days separated by ≥72 hours. The significance was set at $p \leq 0.05$ for all statistical analyses. The mean velocity (MV) maintenance was significantly higher for RR compared with TS (87.70 ± 4.50% vs. 84.07 ± 4.48%, respectively; $p < 0.01$, $d = 0.35$). Rating of perceived exertion (active muscles) was significantly lower for RR compared with TS (5.38 ± 1.42 vs. 6.08 ± 1.43, respectively; $p = 0.02$, $d = -0.35$). Rating of perceived exertion (overall) was also significantly lower for RR compared with TS (5.60 ± 1.40 vs. 6.48 ± 1.49, respectively; $p = 0.02$, $d = -0.37$). The relative strength ratio (relative strength ratio; squat 1RM: body mass) was significantly correlated with the difference in MV maintenance between RR and TS ($r = -0.34$, $p = 0.02$). No sex-based differences ($p > 0.05$) were found for any dependent variables. Rest redistribution produced significantly higher mean HR (143.25 ± 21.11 vs. 135.05 ± 20.74, $p < 0.01$) and minimum HR (102.77 ± 19.58 vs. 95.97 ± 22.17, $p < 0.01$). Subjects were better able to maintain velocity with RR compared with TS, while experiencing less perceived effort. Rest redistribution can be recommended for both men and women, but very strong individuals may not improve their velocity maintenance with RR to the same extent as less strong individuals.

Key Words: cluster sets, velocity, power, resistance training, heart rate, lower body

Introduction

Power production is highly correlated to athletic ability in strength and power sports (28) and is a differentiating factor between levels of athletic competition (1). As the product of force and velocity, power represents both strength and speed capabilities and their interaction (4). Training with maximal intended velocity is crucial for maximizing strength gains and power production (11,33). Traditional resistance training occurs in sets of repetitions that are performed consecutively, with each set separated by rest periods. However, traditional sets (TS) of more than a few repetitions cause large decreases in velocity, inherently limiting maximal power production during acute resistance training sessions (2,41).

Cluster sets (CS) are a mode of strength and power training that have been shown to increase velocity and power production compared with TS (20,45). The most commonly studied CS paradigms add short rest periods (~15–45 seconds) in the middle of sets to allow time for partial recovery (20,45). However, the practicality of CS structures has been called into question, as CS inherently increase the total training time (46). Rest redistribution (RR) is a variation of CS in which the long interset rest periods of TS are divided and "redistributed" into shorter duration rest periods, maintaining the same total rest and training time as TS (45). The major benefit of RR over TS that has been observed is a greater maintenance of velocity and power over the course of a training session (5,26,52). Rating of perceived exertion (RPE) is also lower with RR compared with TS during strength training (25) and weightlifting derivatives (17). This interplay of decreased internal training load and higher performance is a compelling argument for the use of RR during strength and power training.

Most RR studies have used relatively homogenous groups without direct comparisons of strength level in terms of the velocity augmentation effect from RR. In one study, hormonal and mechanical responses to RR were similar between resistance trained and untrained groups of men (31,32). In the only other study to suggest an interaction between absolute strength level and RR efficacy, RPE during RR was lower for stronger subjects (16). Both studies used dichotomous groupings rather than a wide array of strength levels (16,31,32). Jukic and Tufano (16) reported that all subjects experienced a decrease in velocity from beginning to end of a squat protocol with TS, but some subjects were deemed high responders to RR and increased their velocity throughout the RR training session. Because of high strength capacities and the advanced training status of these subjects, this phenomenon of varying responses deserves a more in-depth investigation with respect to the relationship between strength and the efficacy of RR, and perceived exertion across a more heterogeneous sample.

Thus far, RR investigations have examined primarily men, with only one study evaluating men and women who completed the same protocol. Torrejón et al. (44) demonstrated similar velocity responses between men and women for a high-intensity,

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low-volume bench press protocol with short rest periods. In a study examining single sets to failure, men and women completed the same number of repetitions at the same relative loads (35). During multiple sets of bench press to failure, women completed more repetitions with short rest periods compared with men, but sex-related differences were eliminated when absolute and relative strength were included as covariates (36). In addition, both sexes reported the same perceived exertion during fatiguing protocols at the same relative intensities (35). However, it is unknown whether RR set configurations will affect the apparent mechanical and perceptual similarities between sexes when relative loads are used.

The cardiovascular response to RR has been studied as a potential mechanism for increased performance. The heart rate was higher during the 20–40 minutes recovery period after TS compared with RR (39), which mirrored the heart rate variability response indicating increased parasympathetic withdrawal after TS. The heart rate variability studies also show an augmentation of this response when repetitions are performed closer to failure (10,19) with it being either more pronounced with RR than TS (39) or similar between protocols (21). The heart rate was higher during and after repeated isometric knee extensions using longer duration contraction and recovery periods, with both protocols having equivalent total contraction time and work: rest ratios (37). The single-repetition model also produced lower HR during exercise compared with multirepetition sets of the leg press (23). This research would suggest that TS produces a greater HR response; however, HR during exercise has not been reported with an RR model. Furthermore, the practical ease of HR data collection and analysis would provide researchers and practitioners with additional information on the efficacy of RR.

The primary purpose of this study was to determine the differences between TS and RR protocols in terms of external load (velocity maintenance and decline, work) and internal load (perceived exertion and heart rate). We hypothesized that velocity maintenance would be higher, and perceived exertion would be lower during RR compared with TS. To determine applicability across various populations, a secondary purpose was to examine the influence of sex and strength on the efficacy of RR compared with TS protocols.

Methods

Experimental Approach to the Problem

A repeated-measure, counterbalanced, randomized design was used to compare the effects of RR and TS on kinematic, perceptual, and autonomic responses during the free-weight barbell back squat. During visit 1, subjects completed a 1 repetition maximum (1RM) assessment. During visits 2 and 3, subjects performed 40 repetitions of the barbell squat with 65% 1RM load with either TS (4 sets of 10 repetitions, 3-minute rest) or RR (10 sets of 4 repetitions, 1-minute rest), in a randomized order. Traditional sets and RR were constructed to have an equivalent number of repetitions, total rest time, and session duration. A velocity test was administered before and after the training sessions to assess fatigue. A linear position transducer recorded kinematic variables during all testing sessions and RPE scores were recorded after each set. All sessions were ≥72 hours apart to allow for the dissipation of fatigue. Subjects were asked to maintain their usual eating and exercise habits, and refrain from strenuous exercise for 48 hours before testing and alcohol consumption for 24 hours before testing. All tests were performed at the same time of day for each subject. Figure 1 details the study design.

Subjects

Subjects were 30 resistance-trained men (mean ± *SD* age 22.33 ± 3.45 years, height 174.62 ± 6.63 cm, body mass 80.86 ± 11.39 kg, squat 1RM 131.20 ± 24.17 kg, 1RM: body mass ratio [relative strength ratio; RSR] 1.64 ± 0.34, resistance training experience 5.02 ± 2.30 years, and body fat percentage 18.64 ± 6.24%) and 15 resistance-trained women (mean ± *SD* age 22.20 ± 3.34 years, height 160.27 ± 5.89 cm, body mass 62.23 ± 10.37 kg, squat 1RM 83.00 ± 16.72 kg, RSR 1.34 ± 0.17, resistance training experience 3.60 ± 2.05 years, and body fat percentage 25.51 ± 4.15%). All subjects reported having ≥1 year of resistance training experience including performing the back squat × ≥1 per week, an RSR >1, and no injuries within the previous 6 months. Before participating in the study, all procedures, risks, and benefits were explained, and questions were answered. Each volunteer then signed written informed consent documents in order to participate in the study and completed a Physical Activity Readiness Questionnaire (PAR-Q+) and a medical history and activity questionnaire to assess their physical ability to participate in the study. This study was approved by the Institutional Review Board of the University of Central Florida.

Procedures

Anthropometrics and Body Composition. Before the first session, subjects were asked to be sufficiently hydrated and to have abstained from food consumption for a minimum of 2 hours and alcohol for a minimum of 12 hours. On arrival to the laboratory, height and body mass were measured using a stadiometer and scale (Health-o- meter Professional Scale, Model 500 KL; Pelstar, Alsip, IL). The body composition was measured by a noninvasive bioimpedance spectroscopy (BIS) device (SOZO; ImpediMed, Brisbane, Australia). Subjects were encouraged to void their bladder and bowels to ensure no additional weight before the BIS measurement. After removing their shoes, socks, and all jewelry, subjects stood still on the device platform while contacting the electrodes for approximately 20 seconds. All BIS procedures followed the manufacturer's guidelines.

One Repetition Maximum Assessment. One repetition maximum was assessed for the free weight barbell back squat to determine each subjects' 1RM and load for the experimental sessions and velocity test (described in the next section). The 1RM assessment began with 5 minutes of submaximal cycling at ~50% effort, followed by a 5-minutes dynamic warm-up consisting of 5 on each side of the following stretches: forward lunge, bent-over hamstring, reverse lunge, walking quad, straight-leg march, walking knee lift, walking figure 4, side lunge, and 5 submaximal countermovement jumps (~50% maximal effort). After a 1-minute rest, subjects squatted with 20 kg (barbell only) for 8 repetitions, 30 kg for 6 repetitions, and beginning at 40 kg, they performed 3 repetitions of a load <50% projected or estimated 1RM (light), 2 repetitions of a load between 50 and 80% 1RM (medium), and 1 repetition of a load >80% 1RM (heavy). This protocol was based on a previous study (41). There were 2-, 3-, 4-, and 5-minute rest periods after the warm-up, light, medium, and heavy sets, respectively. Weight was added in smaller increments once needed, and the test was ended when a successful lift was

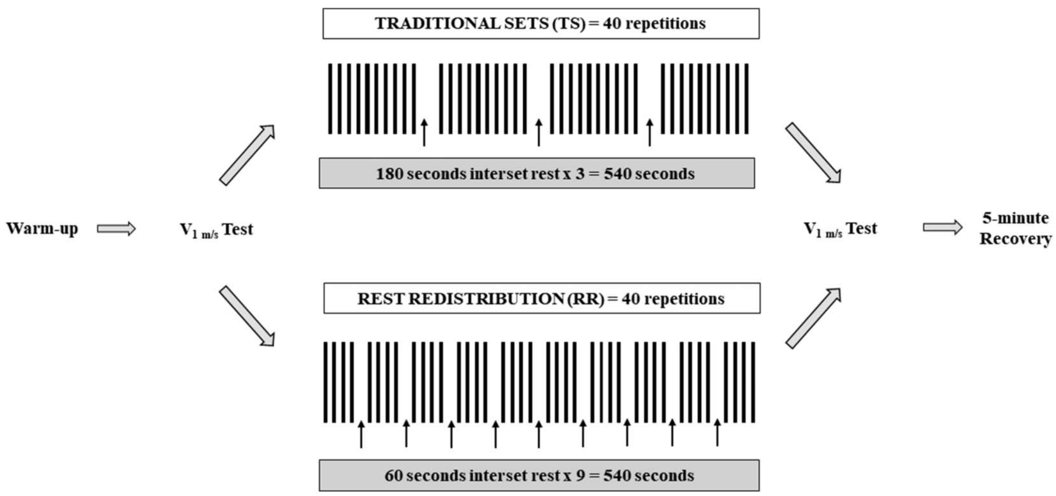

Figure 1. Study design.

completed, and it was determined that no more weight could be added. The relative strength ratio (RSR) was calculated as: 1RM/ body mass. All weights used in the study were weighed on the same scale (Health-o- meter Professional Scale, Model 500 KL; Pelstar), and only weights accurate to the 0.1 kg were used to ensure consistency.

Subjects were instructed to start each repetition in a fully upright position before lowering themselves under control to the bottom of the squat position. With no pause at the bottom, they stood up as explosively as possible until the top of the movement when they paused slightly to ensure full hip and knee extension. For every repetition during the test, and all squats performed in this study, subjects were instructed to "explode out of the bottom" and maintain foot contact with the floor. Full depth was defined as the hip crease being below the patella and was confirmed visually by a Certified Strength and Conditioning Specialist (NSCA—CSCS) and quantitatively by the researcher ensuring that the displacement recorded during the warm-up sets was replicated during the maximal attempts (34).

A linear position transducer (Tendo Power Analyzer V-316; Tendo Sports Machines, London, United Kingdom) was used to collect kinematic data during all sets. It consisted of a sensor unit Velcro strapped to the end of the barbell and connected to a Kevlar cord, enabling measurement and calculation of depth, concentric phase MV, and eccentric phase MV. The Tendo Power Analyzer was previously found to be highly valid when compared with 3D motion capture during free weight barbell back squats (9). For loads with multiple repetitions, the repetition with the highest MV was used for analysis (42). Least squares regression was used to calculate the regression equation for MV from % 1RM to be used in experimental sessions (65% 1RM) and to calculate the load for the velocity test (the absolute load that would be predicted to have a MV of 1 $m{\cdot}s^{-1}$). The correlation between %1RM and MV was nearly perfect ($R^2 = -0.96 \pm 0.03$ [range = -0.89 to -0.99]).

Velocity ($V_{1m/s}$) Test. Fatigue was evaluated by comparing the results of a velocity test at the end of the warm-up and again 1 minute after the RR and TS sessions (11). The $V_{1m/s}$ test consisted of performing 3 repetitions at a load that corresponded to MV ~1 $m{\cdot}s^{-1}$ based on each subject's 1RM regression equation. For the pretest, after performing the same general and dynamic warm-up as in the 1RM test described above, subjects performed a squat warm-up of 25% 1RM for 8 repetitions, followed by 50% 1RM for 5 repetitions with 2 minutes of rest between warm-up sets and before the velocity test. The test was modified to assess the free-weight barbell back squat using MV from a similar procedure previously described by Luis Sanchez-Medina and Gonzalez-Badillo (41) using a Smith machine and mean propulsive velocity as the dependent variable and has not been used. All $V_{1m/s}$ tests included constant verbal encouragement from the researchers to give maximal effort. The average MV of the 3 repetitions was used for analysis. The mean velocity decline of the $V_{1m/s}$ test (MV $Decline_{V1m/s}$) was calculated as: (MV $POST_{V1m/s}$ − MV $PRE_{V1m/s}$)/ MV $PRE_{V1m/s}$ 100.

Rest Redistribution and Traditional Sets. During visits 2 and 3, subjects performed either a TS or RR free weight barbell back squat after completing the same general and dynamic warm-up as the 1RM session, followed by the squat-specific warm-up and velocity pretest as described above. The protocols for TS and RR were based on several studies (16,26,30,48) and consisted of the following: TS: 4 × 10 @ 65% 1RM, 3 minutes interset rest; RR: 10 × 4 @ 65% 1RM, 1 minute interset rest. These training sessions have equal work: rest ratio such that the total training session is the same duration and includes the same number of total repetitions (40) and rest time (540 seconds) to make implementation as practical as possible (45). These schemes were also designed to guarantee that subjects with widely varying resistance experience and relative strength would complete all repetitions (32).

To ensure that each set started as soon as the rest period concluded, the evaluator gave each subject a 10-second verbal countdown (47) and used a handheld stopwatch during all sets (Accusplit Pro Survivor 601X 3v.1; Pleasanton, CA). Rest periods ended once the subject began the descent portion of the squat after unracking the bar and standing still for a moment in a stable, upright position. The rest periods began when the subject achieved full hip and knee extension during the last repetition of the set. All subjects stood during the rest periods for standardization purposes. Similar to the 1RM assessments, subjects were instructed and verbally encouraged to perform the eccentric phase under control and the concentric phase as fast as possible while keeping both feet on the ground. The total time of each protocol was recorded for later analysis. All sessions were overseen and spotted by the same CSCS as in the 1RM testing. Depth data from the 1RM session and the experimental sessions were shown to each subject as needed to ensure squat depth throughout the workout (34). In addition, eccentric velocity feedback was provided to the subjects after each set to ensure consistency. Subjects wore the same footwear on RR and TS as they did during the 1RM testing day.

MV maintenance and MV decline were calculated as follows for the first 20, last 20, and all 40 repetitions of RR and TS:

$$\text{MV Maintenance} = 100 - \left(\frac{[\text{repetition with highest MV} - \text{mean MV of other repetitions}]}{\text{repetition with highest MV}} \times 100\right)$$

$$\text{MV Decline} = \left(\frac{[\text{repetition with lowest MV} - \text{repetition with highest MV}]}{\text{repetition with highest MV}} \times 100\right)$$

The mean velocity maintenance was modified from a previous study, with the mean of all repetitions in the protocol being replaced with the mean of all repetitions other than the highest value (47). Time-under-tension (TUT; [displacement/velocity]) was calculated during the concentric and eccentric phases of the barbell back squat and then summed. Power was not analyzed, as the Tendo calculates power as the product of force (weight of bar) and velocity, and the weight of the bar was constant within and across protocols.

Rating of Perceived Exertion—Active Muscles and Overall. The OMNI-Resistance Exercise Scale (OMNI-RES) was administered at the end of each set to determine differences in RPE for both active muscles (AM) and overall (OA). The OMNI-RES has been validated for measuring RPE during resistance exercise (27,38). Familiarization with the OMNI-RES was provided during the 1RM testing session.

Heart Rate Response. The heart rate (HR) was recorded for the squat warm-up, exercise session, and 5-minute seated recovery period during RR and TS using a mobile application (Elite HRV, Elite HRV LLC, Asheville, NC) on a tablet computer (iPad; Apple Inc., Cupertino, CA). Raw data were downloaded and analyzed using software (Kubios HRV Analysis v3.3; Kubios OY, Kupio, Finland). Each window (warm-up, exercise, and recovery) was analyzed separately for maximal heart rate (HR_{max}), minimum heart rate (HR_{min}), and mean heart rate (HR_{mean}).

Statistical Analyses

Before conducting statistical procedures, dependent variables were assessed for normality with the Shapiro-Wilks test. All dependent variables were normally distributed. Paired t tests were used to examine differences between RR and TS for kinematic variables from the training sessions and $V_{1m/s}$, and HR and HRV variables. Separate 2-way ANOVAs (analysis of variance) (condition × time) for RPE-AM and RPE-OA were used to compare values at the midpoint and end of RR (sets 5 and 10, respectively) and TS (sets 2 and 4, respectively). A 2-way ANOVA (condition × time) was used to examine differences in MV during the $V_{1m/s}$ test. Bonferroni post-hoc tests were used to detect differences between specific sets. Cohen's d effect sizes were calculated for each dependent variable, interpreted with magnitude thresholds of 0–0.2, 0.2–0.6, 0.6–1.2, 1.2–2.0, and >2.0 as trivial, small, moderate, large, and very large, respectively (14).

Simple pairwise correlations were run to analyze correlations between RSR and all kinematic variables as well as RPE. Pearson's product moment correlation coefficients (r) were interpreted as follows: trivial (<0.1), small (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), or practically perfect (>0.9) (14). One-way ANOVAs were used to determine differences in kinematic variables between subjects grouped by RSR: RSR 1–1.25, RSR: 1.25–1.50, RSR: 1.50–1.75, and RSR: >1.75. These groupings were chosen based on quartiles for ease of interpretation. Three-way mixed factorial (condition × group × time) ANOVAs were conducted to determine differences between RSR groups for RPE at the midpoint and end of RR and TS workouts. Tukey's post-hoc follow-ups were run in the event of a significant F-value. Two-way mixed factorial (sex × time) ANOVAs were conducted to determine differences between men and women for RPE at the midpoint and end of RR and TS workouts. Independent t tests were conducted to determine sex-based differences in MV maintenance, MV decline, MV $\text{decline}_{V1m/s}$, and HR. Within-subject reliability for the velocity test and the first 4 repetitions of RR and TS were assessed with 2-way random intraclass correlation coefficients ($ICC_{2,k}$) to account for random and systematic error (51). ICC's were interpreted as follows: 0–0.1, 0.1–0.3, 0.3–0.5, 0.5–0.7, 0.7–0.9, and 0.9–1.0 = trivial, small, moderate, large, very large, and nearly perfect, respectively (14).

Significance for all statistical tests was defined as an alpha level of $p \leq 0.05$. Statistical analysis was performed using an open-source statistical software package (JASP, v0.11.1, University of Amsterdam, Netherlands).

Results

Kinematics

Kinematic variables (mean ± SD) and results of the statistical comparisons are presented in Table 1 for 45 subjects. Because of missing depth data for 4 subjects, depth, TUT, and work are

Table 1
Dependent kinematic variables for rest redistribution (RR) and traditional sets (TS) for all subjects (n = 45).*†

Variable (units)	RR	TS	Percent difference	p	Cohen's d (95% confidence interval)
MV all repetitions ($m \cdot s^{-1}$)	0.74 ± 0.09	0.70 ± 0.09	6.03	<0.01	1.00 (0.64 to 1.35)
MV repetitions 1–20 ($m \cdot s^{-1}$)	0.75 ± 0.09	0.72 ± 0.09	4.17	<0.01	0.74 (0.40 to 1.06)
MV repetitions 21–40 ($m \cdot s^{-1}$)	0.73 ± 0.09	0.67 ± 0.09	8.96	<0.01	1.14 (0.76 to 1.52)
MV maintenance (%)	87.70 ± 4.50	84.07 ± 4.48	3.63	<0.01	0.89 (0.54 to 1.23)
MV decline (%)	−26.70 ± 9.67	−33.07 ± 7.72	6.37	<0.01	0.81 (0.47 to 1.15)
Eccentric MV ($m \cdot s^{-1}$)	0.71 ± 0.15	0.70 ± 0.16	1.43	0.59	0.08 (−0.21 to 0.37)
Depth (cm)‡	62.01 ± 10.02	60.92 ± 9.88	1.79	0.02	0.45 (0.13 to 0.76)
Concentric work (J)‡	18,995 ± 6,327	18,637 ± 6,158	1.92	0.01	0.42 (0.10 to 0.74)
TUT (s)‡	70.79 ± 11.39	71.24 ± 10.26	−0.63	0.63	−0.08 (−0.38 to 0.23)
Total session time (s)	664 ± 30	658 ± 35	0.94	0.16	0.21 (−0.08 to 0.51)

*MV = mean velocity; TUT = time under tension.
†Data are presented as mean ± *SD*. Unless noted, mean velocity (MV) is reported for the concentric phase alone.
‡n = 41.

analyzed and presented for 41 subjects. Reliability was nearly perfect for MV of the first 4 repetitions of each protocol ($ICC_{2,k}$ = 0.91, *SEM* = 0.04 $m \cdot s^{-1}$). Figure 2 displays MV data for all repetitions.

Rating of Perceived Exertion

For RPE-AM, there was no interaction between condition and time. There were significant main effects for both condition (p = 0.02, partial η^2 = 0.11) and time (p < 0.001, partial η^2 = 0.87). Collapsed across time points, RPE-AM was significantly lower for RR compared with TS (5.38 ± 1.42 vs. 6.08 ± 1.43, respectively; p = 0.02, d = − 0.35). Rating of perceived exertion increased significantly from midpoint to end of protocol for RR and TS (p < 0.01, d = 2.61).

For RPE-OA, there was a significant interaction between condition and time (p = 0.04, partial η^2 = 0.09). Follow-up tests revealed that RPE-OA was lower for RR compared with TS at the midpoint (5.47 ± 1.44 vs. 6.13 ± 1.58, respectively; p = 0.01, d = −0.50) but similar at the end of the protocol (7.38 ± 1.56 vs. 7.67 ± 1.60, p = 0.20, d = −0.19). Main effects were found for both condition (p = 0.02, partial η^2 = 0.12) and time (p < 0.01, partial η^2 = 0.85). Collapsed across time points, RPE-OA was significantly lower for RR compared with TS (5.60 ± 1.40 vs. 6.48 ± 1.49, respectively; p = 0.02, d = −0.37). Rating of perceived exertion-OA increased significantly from midpoint to end of protocol for RR and TS (p < 0.01, d = 2.34).

Velocity ($V_{1m/s}$) Test

The average test load was 42 ± 11% 1RM. Depth and eccentric velocity were not different between protocols (p > 0.05). Reliability was very high for MV $PRE_{V\ 1m/s}$ ($ICC_{2,k}$ = 0.80, *SEM* = 0.05 $m \cdot s^{-1}$). There was an interaction effect for condition × time (p < 0.01, partial η^2 = 0.20), with significant main effects for condition (p < 0.01, partial η^2 = 0.26), and time (p < 0.01, partial η^2 = 0.65). There was no difference in MV $PRE_{V\ 1m/s}$ between conditions, and MV $POST_{V1m/s}$ was significantly higher for RR compared with TS (1.01 ± 0.08 and 0.96 ± 0.09, respectively; p < 0.01, d = 0.75). The mean velocity $decline_{V1m/s}$ was significantly lower for RR compared with TS (−3.41 ± 5.47 and −7.56 ± 5.84, respectively; p < 0.01, d = −0.52).

Strength and Sex-Based Differences

RSR was not correlated with MV decline, TUT, RPE, or MV $decline_{V1m/s}$; however, it was significantly correlated with the difference in MV maintenance between RR and TS (r = −0.34 [95%

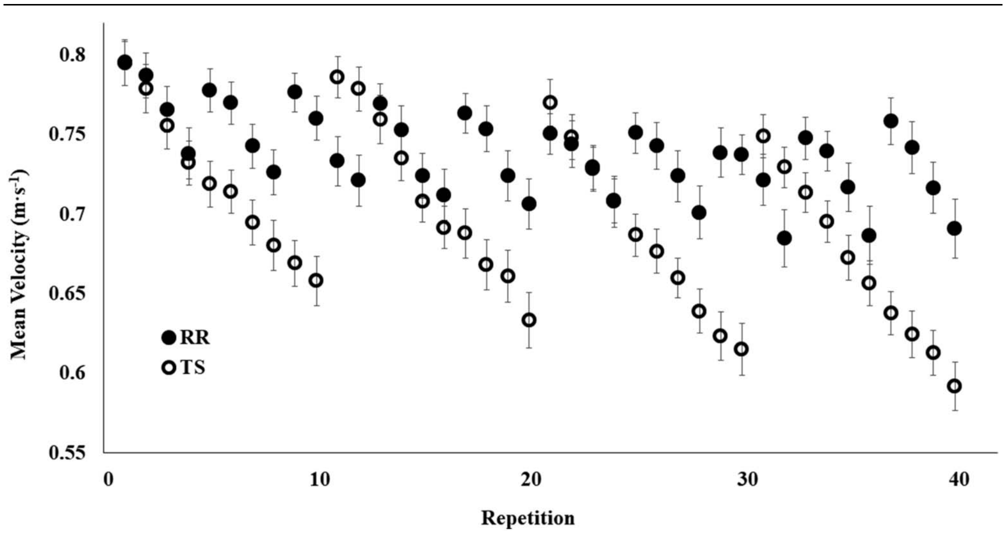

Figure 2. The mean velocity across all repetitions of rest redistribution (RR) and traditional sets (TS). Bars represent *SE*s.

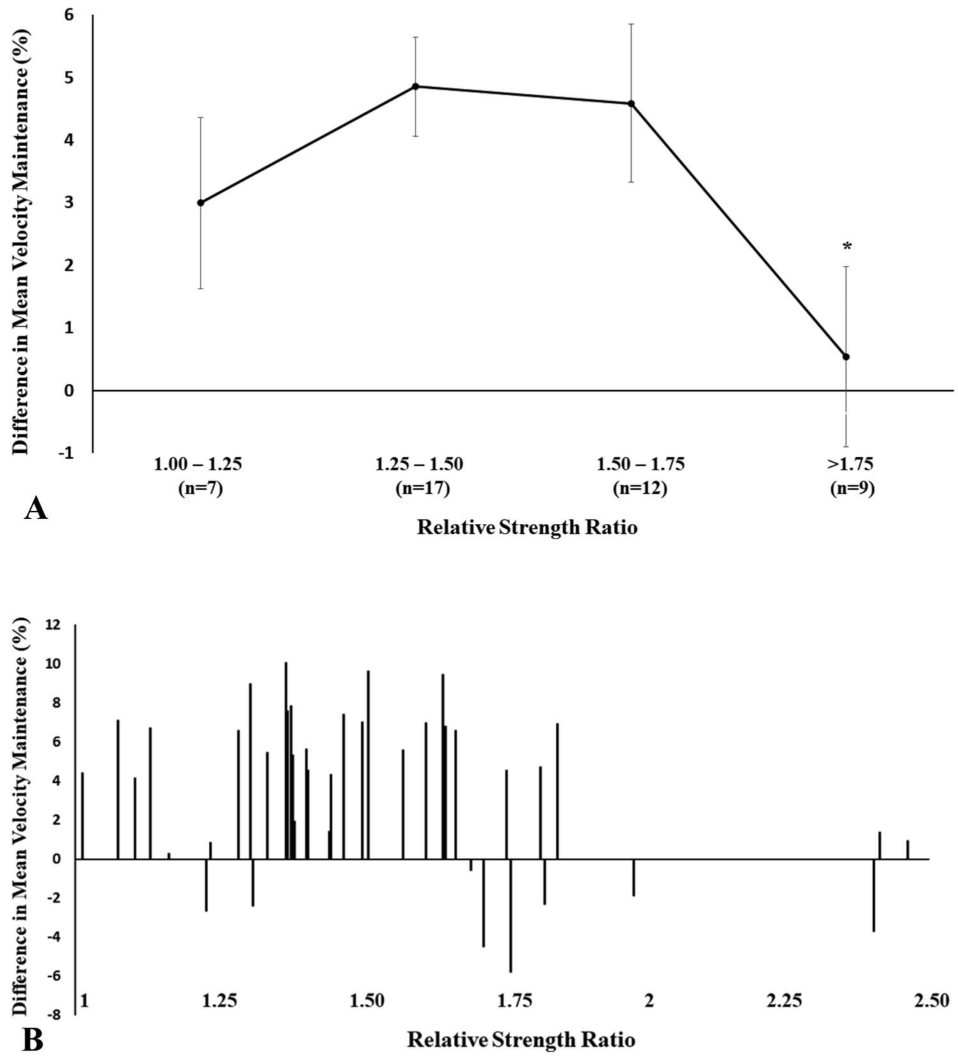

Figure 3. The effect of the relative strength ratio (RSR) on mean velocity (MV) maintenance differences between protocols. A) Difference in MV maintenance between protocols and RSR, with RSR increasing along the *x*-axis; (B) Difference in MV maintenance between protocols across strength groupings. Bars represent standard errors. *p = 0.05 compared with RSR 1.25–1.50.

confidence interval −0.57 to −0.05], $p = 0.02$). A significant effect of RSR group on differences in MV maintenance was found ($p = 0.05$, partial $\eta^2 = 0.17$; see Figure 3 for graph). Post-hoc testing indicated a significant difference between RSR 1.25–1.50 and RSR >1.75 ($p = 0.05$, $d = 1.18$) and nonsignificant differences but moderate effect sizes between RSR >1.75 and both RSR 1.00–1.25 ($p = 0.59$, $d = -0.61$) and RSR 1.50–1.75 ($p = 0.10$, $d = 0.93$). There were no interaction effects between RSR groups and either protocol or time point for RPE-AM or RPE-OA.

No sex-based differences ($p > 0.05$) were found for MV maintenance, MV decline, RPE, HR, or the differences in these variables between protocols.

Heart Rate Response

Because of technical issues with the heart rate monitors and software, 37 complete sets of HR data were analyzed (men: $n = 24$; women: $n = 13$). There were significant differences in HR variables during the exercise period (Table 2). However, there were no significant differences ($p > 0.05$) for HR variables during the warm-up and recovery periods.

Discussion

This study sought to determine differences in velocity, perceived exertion, and the heart rate response between RR and TS

Table 2

Heart rate (HR) during rest redistribution (RR) and traditional set (TS) protocols (n = 37).*

Variable (units)	RR	TS	p	Cohen's d (95% confidence interval)
Mean HR (b·min^{-1})	143.25 ± 21.11	135.05 ± 20.74	<0.01	0.83 (0.46 to 1.19)
Minimum HR (b·min^{-1})	102.77 ± 19.58	95.97 ± 22.17	<0.01	0.46 (0.12 to 0.79)
Maximum HR (b·min^{-1})	166.66 ± 18.76	173.23 ± 14.50	<0.01	−0.91 (−1.29 to −0.53)

*Data are presented as mean ± *SD*.

protocols during 40 repetitions of the free weight barbell back squat at 65% 1RM. Our main findings were (a) MV was better maintained with RR than TS during the protocol and on a velocity post-test, (b) RPE was lower during RR, (c) relative strength was moderately negatively correlated with velocity augmentation during RR compared with TS, (d) RR and TS had different heart rate responses such that TS may provide higher maximal stress during training and short-term recovery, and (e) men and women did not differ on the velocity or RPE response to RR and TS.

The RR protocol was more efficacious than the TS protocol for maintaining velocity across the 40 repetitions, with the difference in velocity nearly doubling between protocols over the second half of the workout (8.96%) compared with the first (4.17%). This primary finding is in agreement with most of the RR research literature (18,26,32). Near-infrared spectroscopy of the vastus lateralis revealed higher levels of total hemoglobin and oxygen saturation throughout an isokinetic leg extension RR protocol compared with TS (50). Tufano and colleagues (51) postulated that the increased local circulation was due to the greater number of sets during RR providing more opportunities for the mechanical pumping action of the lower body to increase venous return, remove lactate, and replenish phosphocreatine (PCr). Although these variables were not measured by Tufano et al. (50) or in the current study, this theory is supported by seminal studies which observed that fewer consecutive repetitions led to lower lactate levels by less contribution from anaerobic metabolism (13), and PCr depletion and lactate production were shown to be highly negatively correlated with power output (3,12).

In one of the few studies with equivocal findings for RR, MV but not MV maintenance was compared using a 6RM (~85% 1RM) load for Smith machine bench press over 24 repetitions, with short intraset rest intervals (15 seconds) or inter-repetition rest of 39 seconds (44). Although a direct comparison is not possible because of the different CS subtypes and muscle groups used in the aforementioned study and the current one, our findings suggest RR may be more preferable than TS during high-volume, highly fatiguing protocols. The mean velocity maintenance is a more salient variable than MV because it considers the highest velocity of a session and compares the rest of the repetitions to that number. Although both MV and MV maintenance were significantly higher with RR in the current study, the percent difference between conditions was greater for MV than MV maintenance (6.03 vs. 3.63%), suggesting that MV alone may inflate or mitigate differences between protocols depending on the amount and direction of random or systematic error inherent in multiday testing.

Greater MV decline in the TS velocity post-test suggests that RR may better prepare trainees for subsequent exercise performance in an expanded training session. It should be noted that the 1-minute rest between the last repetition of the protocol and the first repetition of the velocity test may have positively biased the results for RR, as the last set completed was 4 repetitions as compared with 10. However, the total volume performed before the velocity test was identical. In a previous study, when subjects were instructed to lift with maximum velocity versus half of their respective maximal velocity, they experienced greater decline on a similar velocity test (11). In the current study, faster velocities during the training session led to less decline on the post-test. As this is the first study to examine, a recent meta-analysis suggests that improvements in RR vs. TS post-tests may be less extreme than intrasession velocity changes (15), and thus a certain fatigue threshold would have to be reached to realize differences. Cuevas-Aburto et al. (5) saw no difference pre-post on countermovement jump performance after low-volume (18 repetitions) RR and TS schemes although MV was higher during RR protocol. A possible neuromuscular mechanism for RR's faster recovery is that muscle properties such as contraction time may recover more quickly after an RR protocol compared with TS, but this requires further investigation (50). As this is the first study to examine the $V_{1m/s}$ test before and after RR, more research is needed to determine the usefulness of this test in both research and practice.

In line with previous observations (17,25), the currently reported RPE values over the entire protocol were lower with RR compared with TS. Rating of perceived exertion was likely higher during TS because of the parallel relationships between RPE and both time taken to complete individual repetitions (7) and number of consecutive repetitions performed (22). In the current examination of AM and OA independently, the equivalent RPE-OA scores between RR and TS for the final set (7.4 and 7.7, respectively) would indicate that both protocols were perceived as requiring a similar level of exertion. The lower perception of effort during the first half of the RR protocol compared with TS seems to have accelerated over the second half of the session, yielding similar values on completion of the training session. Nonetheless, subjects achieved a greater increase in MV with RR compared with TS during the second half compared with the first. The mechanical benefits of the RR set structure may be more prolonged than the perceptual response.

There is a lack of research directly examining the effect of strength on velocity response to RR. Oliver et al. (32) observed that trained versus untrained men showed similar patterns of velocity/force/power maintenance with RR and TS. In another RR study, when subjects were split into 2 groups based on absolute strength (above and below a 150 kg 1RM squat threshold) for analysis, there was no difference in the velocity and power response to RR (16). However, the average strength across all subjects was high (RSR = 1.82 ± 0.33) because they were weightlifters or track and field athletes. The authors suggest the highly fatiguing nature of their protocol may have obscured any effect of strength on differences in MV maintenance. In the current study, relative strength was moderately negatively correlated with MV maintenance. Further breakdown of this effect by investigating RSR groups revealed that the strongest subjects in our sample (RSR: >1.75, n = 9) showed a lesser enhancement of velocity maintenance from RR compared with moderately strong (RSR: 1.25–1.50, n = 17). A modest curvilinear relationship between strength grouping and RR efficacy was identified, with the highest RR efficacy for subjects with RSR: 1.25–1.50 and RSR 1.50–1.75 (36).

In a previous study, RR produced greater interindividual variability of responses compared with TS, with 8 of 26 subjects experiencing an increase in velocity after the first repetition during RR, compared with all subjects experiencing a decline during TS (16). In the current study, all subjects had a decline in velocity during RR, albeit less of a decrement on average than during TS. Eight of 45 subjects had a higher MV maintenance during TS, indicating they did not have a positive response to RR training for velocity purposes. These 8 nonresponders had an average RSR of 1.74 ± 0.37, whereas the top 8 responders to RR had an average RSR of 1.39 ± 0.17. Taken together with the negative correlation between RSR and RR efficacy, it seems that RR during high-volume squat workouts may not be as effective for those individuals above a certain strength threshold.

However, it should be noted that the strength group analysis in the current study involved unequal sample sizes, and RSR >1.75 or <1.00 should not be interpreted as rigid guidelines. In addition, because of the enormous interpersonal variability in the number of repetitions that different athletes can lift above their relative velocity thresholds (49), it would seem that RR strategies are likely subject to an inherently individualized response. On a similar note, in the current study, the intentional inclusion of a wide range of strength levels and a random sampling process resulted in 3 outliers with high levels of relative strength compared with the overall group. These very strong individuals did not substantially benefit from RR in terms of velocity maintenance, fitting the trend of the moderate negative correlation. Anecdotally, their personal methods of training may have involved longer rest periods, and the short rest periods during RR may have been insufficient for their recovery.

In the only previous study to have men and women complete both RR and TS protocols, there were no significant sex-based differences in velocity decline (men: −12.1%; women: −11.3%) (44). In the same study, there were nonsignificant differences in average MV with RR compared with TS for women (1.78%) compared with men (−2.78%). Likewise, men and women in the current study demonstrated similar velocity decline and velocity maintenance between protocols. Because of MV maintenance being slightly higher during RR compared with TS for women, there was a nonsignificant small effect for difference in maintenance between sexes. Our results are in line with those of Torrejon et al. (44) and suggest that women have similar but potentially better velocity performance with RR than TS compared with men. Glycolysis becomes a greater contributor to metabolism during longer sets (12,13,41), and men have a higher capacity for glycolysis (40), which may explain why women achieve slightly higher velocity augmentation from RR than men.

The current study is the first to directly examine the influence of sex on RPE during RR and TS and showed similar responses between men and women within and between each protocol. Confirming studies in men, resistance-trained women squatting at similar intensities and volumes as this study reported higher RPE during TS than RR (25). Women and men have also reported similar RPE at the same relative intensities during fatiguing resistance exercise (35), which holds true regardless of training experience (43). A limitation of all sex comparisons in the current study is the unequal sample size of the men and women groups (n = 30 and n = 15, respectively). It would seem that both sexes have similar perceptual and mechanical responses to RR. However, our results do not offer any firm conclusions on the topic, and the potentially unique considerations for sex-based characteristics related to RR can be further explored.

Performing fewer consecutive repetitions during RR led to lower HR_{max}, whereas the shorter rest periods resulted in higher HR_{mean} and HR_{min}. Studies of different set configurations reveal lower HR_{mean} during exercise when sets are single repetition compared with multirepetition (23), or when repeated sets of isometric knee extensions are held for shorter durations (37). The interaction between exercise type, intensity, volume, and rest period seem to determine the cardiovascular response to resistance training. The 60-second rest periods during RR in the current study provided a more consistent cardiovascular stress than TS. However, performing fewer consecutive repetitions enhanced recovery of mechanical abilities and led to lower perceived exertion, as discussed above.

There were no significant differences in HR during the recovery period, but there was a small effect ($d = -0.26$), with TS having a higher HR_{min}. In a study comparing full-body RR vs. TS protocols, HR_{mean} was higher for TS than RR for a 20- to 40-minute recovery period (39). During recovery, the peak HR has been shown to be strongly positively correlated with lactate (29). Lactate levels were previously shown to be higher during longer, more fatiguing sets (41), and Denton and Cronin (6) observed that lactate returned to baseline levels faster after RR than TS. These data suggest that cardiovascular and metabolic recovery may be slower after TS compared with RR, and higher HR_{max} during a TS session may be a determining factor.

Equivalencies between protocols for eccentric MV seem to support the use of a self-regulated eccentric tempo during RR protocols. This finding is in agreement with previous research (16), and the current results may have been further enhanced by providing eccentric MV feedback to subjects after each set. Interestingly, squat depth was different between protocols despite the researchers using the same knee below hip-crease cueing and quantitative feedback. Subjects achieved greater squat depth during RR, which led to higher work during the training session. When examining clean pulls, weightlifters reportedly achieved greater vertical barbell displacement with RR compared with TS (18). The difference in depth (i.e., displacement) observed in the current study despite coaching feedback replicates practical situations in which there are slight variations from repetition to repetition and provides support for the effectiveness of RR compared with TS. Quantitatively, the variation in depth across the repetitions was minimal and similar between protocols (coefficient of variation: RR = 4.64%, TS = 4.38%). Thus, in the presence of constant encouragement and feedback, enhanced kinematic performance (greater barbell displacement, concentric work, and movement velocity) would be expected with RR, which may be desirable during high-volume training blocks.

Several limitations of this study should be noted. There was no objective replication of foot positioning for the repetitions during the experimental sessions. Visual inspection by the subject and the researcher is subject to error, although these conditions, such as differences in depth, are inherent in any practical strength and conditioning setting. Finally, the phase of the menstrual cycle was not controlled for in this study. However, previous research has shown no changes in acute velocity performance across the menstrual cycle (8), and a recent meta-analysis revealed trivial effects of the menstrual cycle phase on strength (24).

Practical Applications

Subjects were better able to maintain velocity with RR compared with TS, while also experiencing less perceived effort and squatting to greater depths. Rest redistribution may lead to a faster recovery in velocity performance and involve less maximal cardiovascular stress. Thus, RR may be preferred over TS when acute recovery is paramount. Very strong individuals showed attenuated MV maintenance benefits of RR compared with their less strong counterparts. There were no differences noted across the strength level and sex for perceived exertion, and no differences between men and women for velocity maintenance. Acutely, RR can be recommended for both men and women, but extremely strong individuals may benefit from a more personalized approach to programming.

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