The Effects of Rest Interval Length on Acute Bench Press Performance: The Influence of Gender and Muscle Strength

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Abstract

Ratamess, NA, Chiarello, CM, Sacco, AJ, Hoffman, JR, Faigenbaum, AD, Ross, RE, and Kang, J. The effects of rest interval length on acute bench press performance: the influence of gender and muscle strength. *J Strength Cond Res* 26(7): 1817–1826, 2012. The purpose of this study was to investigate the effects of rest interval (RI) length on bench press performance in subjects with disparity in maximum strength. Two cohorts of subjects performed 3 bench press protocols in random order consisting of 3 sets of up to 10 repetitions with 75% of 1-repetition maximum (1RM) using either 1-, 2-, or 3-minute RIs between sets. In the first cohort, 22 men and women were studied to investigate gender influence. In the second cohort, 23 men were tested for 1RM bench press strength and placed into a low 1RM (mean = 80.7 ± 7.5 kg) or high 1RM (mean = 140.6 ± 11.9 kg) experimental group. The number of successful repetitions completed, average power, and velocity for each set were recorded. Women performed significantly more repetitions than men with 1-minute (26.9 ± 4.4 vs. 21.1 ± 3.5), 2-minute (29.0 ± 2.0 vs. 24.0 ± 4.5), and 3-minute (29.7 ± 1.8 vs. 25.8 ± 5.1) RIs. The magnitude of decline in average velocity and power was significantly higher in men than in women. Total number of repetitions performed was significantly greater in the low 1RM group than in the high 1RM group at 1-minute (21.6 ± 5.0 vs. 18.1 ± 2.0) and 2-minute RIs (24.2 ± 5.4 vs. 21.3 ± 2.8). Significant negative correlations were observed between 1RM bench press and total number of repetitions completed for 1- and 2-minute RIs ($r = -0.558$ and -0.490, respectively). These data indicate that maximal strength plays a role in bench press performance with varying RIs and suggest that shorter RIs may suffice in women to attain a specific volume.

Key Words resistance exercise, power, velocity, resistance training, weight lifting

Introduction

The length of the rest interval (RI) selected during resistance training is a variable of importance to strength and conditioning professionals. The RI length interacts with other acute program variables including intensity, volume, exercise order, repetition velocity, and it depends on an individual's training goals, fitness level, and the energy system targeted for response (24). The RI length between sets and exercises has been shown to affect the metabolic (23,31), hormonal (4,5,22), and immune cell (26) responses to an acute bout of resistance exercise, including repetition performance (volume and volume load) of subsequent sets (9,20,31,34,36), acute power output (1) and may affect the magnitude of postresistance exercise creatine kinase concentrations (26,34). Studies have shown that during sets performed near or to muscular exhaustion, repetition number, and total volume load decrease with each set in succession when 30- to 2-minute RIs were used (31,32,34,40,42). The acute reduction in resistance exercise volume observed with short RIs (<2 minutes) result in a slower rate of strength gains compared with longer RIs (7,14,29,33) although similar strength increases have been reported between 2- and 4-minute RIs (43) and 1- and 2.5-minute RIs (5). However, high-intensity muscle endurance enhancement may be augmented by short RIs (14).

Gender differences have been observed during comparisons of acute high-intensity exercise responses between men and women. Previous studies have shown that women have lower decrements in force output and faster recovery ability during moderate-to-high-intensity exercise than men do (10,13,19,25,35). Women have been shown to have reduced adenosine triphosphate (ATP) depletion (8), faster ATP recovery (8), lower blood lactate (12,25), lower epinephrine (12), lower respiratory exchange ratio (28), and lower

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glycogen breakdown in type 1 fibers (8) in response to maximal sprint exercise. However, less is known regarding acute resistance exercise responses in women during RI length manipulation. Celes et al. (6) showed that women recover faster than men do after 3 sets of 10 isokinetic knee extensions at $120^{\circ}\cdot s^{-1}$ using 60- and 120-second RIs. Willardson et al. (44,45) showed that during a squat protocol with 1-minute RIs, men needed a 15% reduction in load for each set in succession (to maintain repetition number), whereas women needed only a 10% reduction. Thus, women appear to have lower rates of fatigue and faster recovery during short RIs compared with men but resistance exercise studies directly comparing male and female performances are few.

It has been suggested that gender differences in fatigability observed during high-intensity exercise may be more of a function of strength and power differences rather than gender per se (2). Men have been shown to possess greater absolute strength, power, and lean body mass in the upper and lower body compared with women (37). It may be hypothesized that factors that allow an individual to lift a large absolute amount of weight or express high levels of power (i.e., neural recruitment patterns, firing rate, and synchronization, preponderance of fast-twitch muscle fibers, ATP-creatine phosphate [CP] stores and depletion-repletion rates, muscle architecture, and increased muscle cross-sectional area) coupled with potential limitations in capillary and mitochondrial density, anaerobic enzyme activity, and buffer capacity known to accommodate significant muscle hypertrophy may limit muscle endurance and recovery between sets especially when short RIs are prescribed. Few studies have directly addressed this concept in populations with substantial muscle strength and power disparity. Faigenbaum et al. (9) compared acute resistance exercise performance (3 sets of up to 10 repetitions) using 1-, 2-, and 3-minute RIs in adult men, adolescents, and children and reported that RI length had a more profound effect in adults than in children and adolescents. In fact, children and adolescents performed significantly more repetitions than adults did during protocols with 1- (~28 vs. 18 repetitions), 2- (~29 vs. 21 repetitions), and 3-minute (~30 vs. 24 repetitions) RIs. The adults had a much higher level of maximal strength than did the children and adolescents. In addition, some studies have shown older men and women (with less muscle strength) have faster peak torque recovery during isokinetic knee flexion and extension resistance exercise with short RIs than young adults (3,39). Thus, the impact of absolute differences in muscle strength and power in response to RI manipulation during resistance exercise requires further study.

The RIs have been prescribed based on training goals. For example, long RIs (i.e., at least 2–3 minutes) have been recommended for strength and power multiple-joint exercise training, whereas shorter RIs (i.e., ≤1–2 minutes) have been recommended for muscular endurance training (30). However, these guidelines have been applied generally with little differentiation among individuals of different gender and muscle strength and power because of the paucity of existing data. The effects of individual strength and power disparity in resistance exercise RI prescription are poorly understood. Thus, the purpose of this investigation was to examine the potential influences of gender and muscular strength on the kinetic and kinematic effects of RI length manipulation during resistance exercise. Two subject cohorts were employed to investigate acute bench press performance differences between young women and men and between young men who possessed a mean 60-kg difference in the 1RM bench press. In the first cohort, we addressed the concept of gender differences. In addition, we addressed the concept of maximal strength by performing an analysis of covariance in our first cohort of subjects and we investigated a second cohort of men who possessed great disparity in muscle strength.

Methods

Experimental Design and Approach to the Problem

To examine the primary hypotheses of this investigation, 2 subject cohorts with significant disparity in maximum muscular strength were investigated. The subjects performed 3 bench press protocols in random order consisting of 3 sets of up to 10 repetitions with 75% of their 1-repetition maximum (1RM) using either 1-, 2-, or 3-minute RIs in between sets. In the first cohort, 22 men and women were studied to investigate the possible influence of gender on acute bench press performance. In the second cohort, 23 men were tested for 1RM bench press strength and placed into a low or high 1RM group. Both cohorts allowed us to directly address the gender-specific issue of maximal muscle strength and acute resistance exercise performance, for example, an analysis of covariance in men and women using maximal strength as a covariate in cohort 1 and further addressing the concept in only men with great disparity in maximal strength. The number of successful repetitions completed, average power, and velocity for each repetition of each set were recorded. This study design enabled us to examine the acute performance, kinematic, and kinetic responses to bench press protocols of varying RIs in the subjects with large disparities in muscle strength.

Subjects

In the first cohort, 22 healthy, resistance trained men (age = 22.8 ± 6.5 years; height = 183.1 ± 4.8 cm; body mass = 87.7 ± 10.9 kg; percent fat = 13.0 ± 4.0%; 1RM bench press = 112.4 ± 18.2 kg; relative bench press strength = 1.30 ± 0.24; $N = 11$) and women (age = 20.8 ± 4.5 years; height = 164.8 ± 6.6 cm; body mass = 63.4 ± 10.2 kg; percent fat = 22.0 ± 6.0%; 1RM bench press = 35.8 ± 5.6 kg; relative bench press strength = 0.57 ± 0.08; $N = 11$) with at least 1 year of training experience were selected for this investigation. In the second cohort, 23 healthy, resistance trained men were tested for 1RM bench press strength and subsequently placed into a Low (age = 21.8 ± 3.1 years; height = 178.9 ± 6.0 cm; body mass = 76.8 ± 6.3 kg; percent fat = 10.2 ± 3.2%; $N = 9$) or High 1RM (age = 22.3 ± 5.9 years; height = 179.3 ± 9.2 cm; body

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mass = 95.8 ± 13.8 kg; percent fat = 16.8 ± 3.3%; $N = 14$) group. The Low 1RM group had a 1RM bench press of 80.7 ± 7.5 kg (and relative bench press strength = 1.07 ± 0.15), whereas the High 1RM group had a 1RM bench press of 140.6 ± 11.9 kg (and relative bench press strength = 1.49 ± 0.23). The subjects were selected based on prestudy criteria of a 1RM bench press ≤90 or ≥130 kg to produce 2 groups of subjects with great disparity in 1RM performance. Each subject initiated the study in a trained state (i.e., were currently participating in weight training) were current or former athletes, and none were taking any medications or anabolic steroids known to affect resistance exercise performance. The subjects underwent 1 week of familiarization with study procedures before testing. During this time, height was measured using a wall-mounted stadiometer, body mass was measured using an electronic scale, and body density was determined using 3-site gender-specific skinfold tests (17,18), and percent body fat was calculated using the equation of Siri (38). This study was approved by The College of New Jersey's Institutional Review Board, and each subject subsequently signed an informed consent document before participation. No subject had any physiological or orthopedic limitations that could have affected lifting performance as determined by completion of a health history questionnaire.

Strength Testing

One-repetition maximum bench press strength was assessed before the experimental sessions using a standard protocol (21). A warm-up set of 5–10 repetitions was performed using 40–60% of the perceived 1RM. After a 1-minute RI, a set of 2–3 repetitions was performed at 60–80% of the perceived 1RM. Subsequently, 3–4 maximal trials were performed to determine the 1RM with 2- to 3-minute RI between trials. A complete range of motion and proper technique were required for each successful 1RM trial. Assessment of 1RM bench press enabled calculation of the precise training loads used during the protocols (75% of 1RM). Test-retest reliability for 1RM testing has been consistently high in our laboratory ($R > 0.93$) (9).

Kinetic and Kinematic Assessments

Average bar velocity and power for the each repetition of the bench press was measured with a Tendo Power Output Unit (Tendo Sports Machines, Trencin, Slovak Republic). The Tendo unit consists of a linear position transducer attached to the end of the barbell, which measured linear displacement and time. Subsequently, average bar velocity and power were determined for each repetition. Power and velocity were averaged for each set (for all completed repetitions) so sets 1, 2, and 3 could be directly compared. Fatigue rates (FRs) for velocity and power were calculated by using the following equation for each RI: FR (%) = [(set 1 − set 3)/set 1 × 100] to determine the percent decline in performance over the length of the protocol. Test-retest reliability for the Tendo unit in our laboratory has consistently shown $R > 0.90$ (9,11,15).

Bench Press Protocols

The subjects reported to the laboratory at a standard time of day (to eliminate potential circadian performance variations) on 3 occasions with each protocol session separated by 48–72 hours. Each protocol consisted of performing the bench press exercise with 75% of their predetermined 1RM for 3 sets of up to 10 repetitions per set at the subjects' own self-selected velocity. The acute program variable manipulated was RI length. The subjects performed each protocol using 1-minute (1RI), 2-minute (2RI), or 3-minute (3RI) RIs (in randomized order). Resistance was maintained for each set while repetitions were counted. The subjects were encouraged to target 10 repetitions per set. Repetitions not completed in a full range of motion or those repetitions completed via assistance from a spotter were not counted. The same bench press protocol was used in both study samples. All the subjects were instructed to consume a small meal 1–1.5 hours before testing. In addition, water was consumed ad libitum to ensure hydration during each protocol.

Statistical Analyses

Standard statistical methods were used to calculate means and *SD*s. A 2 (group) × 3 (set number) repeated measures analysis of variance (ANOVA) was used to analyze main effects and interactions in repetition number per set, average power, and average velocity data to determine the effects of RI length across groups. Subsequent Tukey's post hoc tests were used to determine temporal and group differences when significant F ratios were obtained. In addition, a 2 × 3 repeated measures analysis of covariance

Table 1. Bench press repetitions in the cohort of men and women

	Set 1	Set 2	Set 3	Total
1-min Rest interval				
Men	10.0 ± 0.0	7.1 ± 2.3*	4.0 ± 1.7*	21.1 ± 3.5
Women	10.0 ± 0.0	9.3 ± 1.4†	7.7 ± 3.0*†	27.0 ± 4.2†
2-min Rest interval				
Men	9.9 ± 0.3	8.2 ± 2.1*	5.9 ± 2.6*	24.0 ± 4.5
Women	9.9 ± 0.3	9.7 ± 0.8†	8.9 ± 1.7*†	28.5 ± 2.7†
3-min Rest interval				
Men	9.9 ± 0.3	9.2 ± 1.3	7.7 ± 2.8*	26.8 ± 4.2
Women	9.9 ± 0.3	9.8 ± 0.6	9.6 ± 1.2†	29.3 ± 1.8†

*$P \leq 0.05$ from the previous set.
†$P \leq 0.05$ between groups.

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Table 2. Kinetic and kinematic bench press data in the cohort of men and women.*

	Average power (W)			Average velocity ($m \cdot s^{-1}$)		
	1RI	2RI	3RI	1RI	2RI	3RI
Men						
Set 1	319.6 ± 42.0†	316.5 ± 66.8†	307.6 ± 59.1†	0.39 ± 0.06	0.39 ± 0.07	0.38 ± 0.06
Set 2	243.8 ± 34.5†‡	273.7 ± 59.1†‡	285.2 ±65.2†‡	0.30 ± 0.05‡	0.33 ± 0.05‡	0.35 ± 0.06‡
Set 3	208.9 ± 42.9†‡§	236.5 ± 58.7†‡§	264.6 ± 69.9†‡	0.25 ± 0.05‡§	0.28 ± 0.05†	0.32 ± 0.05‡§
Women						
Set 1	112.1 ± 24.1†	108.1 ± 25.4†	108.8 ± 27.7†	0.42 ± 0.07	0.41 ± 0.08	0.41 ± 0.09
Set 2	96.9 ± 29.0†‡	91.2 ± 37.1†‡	108.4 ± 26.9†	0.36 ± 0.08‡	0.39 ± 0.07‡	0.41 ± 0.08
Set 3	86.2 ± 24.7†‡§	95.2 ± 23.6†‡	99.8 ± 24.8†‡§	0.32 ± 0.07†‡	0.36 ± 0.07†‡	0.37 ± 0.07†‡

*RI = rest interval.
†Indicates $p \leq 0.05$ between groups.
‡Indicates $p \leq 0.05$ from set 1.
§Indicates $p \leq 0.05$ from set 2.

(ANCOVA) was employed to analyze total repetitions completed and average power data between male and female groups thereby removing the effects of bench press 1RM strength and relative strength (bench press 1RM [kilograms]/body mass [kilograms]). A 1-way ANOVA was used to analyze total repetitions completed and FR data between groups. To partial out the effects of muscular strength on performance in the cohort of men and women, a 1-way ANCOVA was employed to analyze total repetitions completed and FR data between groups using bench press 1RM strength and relative strength as covariates. Pearson-product moment correlation coefficient indices were calculated for evaluating relationships between bench press 1RM and selected performance variables. For all statistical tests, a probability level of $p \leq 0.05$ denoted statistical significance. Statistical power was determined to be >0.80 for both sample cohorts studied at the 0.05 alpha level.

Results

Bench press repetition data for the first cohort of subjects are presented in Table 1. Significant main effects in set repetition performance were observed during 1RI ($F[2,19] = 38.3$, $p < 0.001$), 2RI ($F[2,19] = 16.0$, $p < 0.001$), and 3RI ($F[2,19] = 6.7$, $p = 0.006$) where repetition numbers decreased during 1RI (sets 2 and 3 in men; set 3 in women), 2RI (sets 2 and 3 in men; set 3 in women), and 3RI (set 3 in men). Significant interactions were observed during 1RI ($F[2,19] = 10.9$, $P = 0.001$), 2RI ($F[2,19] = 6.4$, $p = 0.008$), and a trend was observed during 3RI ($F[2,19] = 3.2$, $p = 0.06$) where the number of repetitions performed during set 2 (1RI and 2RI) and set 3 (1RI, 2RI, and 3RI) were significantly higher in women. Results of ANCOVA showed that repetition performance over 3 sets of the bench press did not differ during 1RI, 2RI, or 3RI when 1RM bench press or relative strength were used as covariates

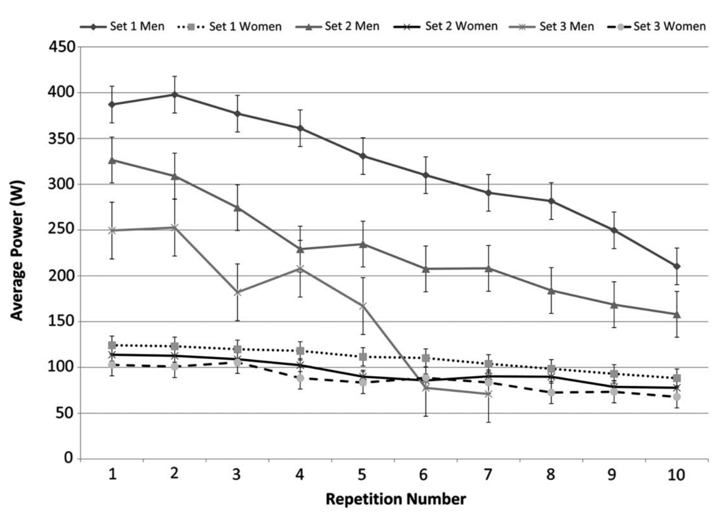

Figure 1. Representative average power obtained during the 1 rest interval (RI) protocol in men and women. Average power (watts) for all 3 sets is depicted. Absent data in set 3 indicate a failure of subjects to reach 10 repetitions. Data depicted are mean ± *SEM*.

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Table 3. Bench press repetitions for the high and low 1RM groups.*

	Set 1	Set 2	Set 3	Total
1-min RI				
High 1RM	9.9 ± 0.3	5.4 ± 1.5†	2.8 ± 0.7†	18.1 ± 2.0
Low 1RM	10.0 ± 0.0	7.8 ± 2.2†‡	3.9 ± 3.0†	21.6 ± 5.0‡
2-min RI				
High 1RM	9.8 ± 0.4	7.0 ± 1.7†	4.5 ± 1.3†	21.3 ± 2.8
Low 1RM	10.0 ± 0.0	8.2 ± 1.9†	6.0 ± 3.6†	24.2 ± 5.4‡
3-min RI				
High 1RM	9.6 ± 0.6	8.3 ± 1.4†	5.4 ± 2.0†	23.4 ± 3.2
Low 1RM	10.0 ± 0.0	8.4 ± 1.9†	6.8 ± 3.2†	25.1 ± 5.1

*RM = repetition maximum.
†$p \leq 0.05$ from the previous set.
‡$p \leq 0.05$ between groups.

($F = 0.08$–3.90, $p = 0.20$–0.93; partial $\eta^2 = 0.009$–0.171). These data indicate that maximal strength significantly influenced acute resistance exercise performance independent of gender. Total repetitions performed over 3 sets were significantly higher in women than men at all RIs. One-way ANCOVA revealed that total repetitions performed did not significantly differ between genders during 1RI ($F = 0.13$–2.56; $p = 0.13$–0.73), 2RI ($F = 0.47$–2.86; $P = 0.11$–0.50), or 3RI ($F = 0.05$–2.90; $p = 0.11$–0.82) when 1RM strength and relative strength were used as covariates indicating that maximal strength influenced total repetitions performed independent of gender. Significant negative correlations were observed between 1RM bench press and total number of repetitions completed for 1RI, 2RI, and 3RI ($r = -0.568$, -0.621, and -0.499, respectively).

Bench press kinetic and kinematic data are presented in Table 2 and Figure 1. For average power, significant main effects were observed in 1RI ($F[2,19] = 83.1$, $p < 0.001$), 2RI ($F[2,19] = 9.5$, $p = 0.001$), and 3RI ($F[2,19] = 9.8$, $p = 0.001$) where reductions were seen with each set in succession during 1RI and 2RI in men and 1RI in women. During 3RI, sets 2 and 3 were lower than set 1 in men, and set 3 was lower than sets 1 and 2 in women. Significant interactions were observed during 1RI ($F[2,19] = 33.4$, $p < 0.001$) and 3RI ($F[2,19] = 5.6$, $p = 0.012$) indicating a slower rate of decline in women. Repeated measures ANCOVA revealed that average power changes over 3 sets during 1RI, 2RI, and 3RI differed between genders ($F = 3.90$–8.04; $p = 0.038$–0.003) indicating that 1RM bench press and relative strength did not influence acute power reductions. One-way ANOVA revealed that average power values were significantly higher in men than in women for most sets and the FRs over 3 sets for 1RI and 3RI were significantly lower in women compared with men (1RI: 34.8 ± 9.9% vs. 22.6 ± 13.1%; 2RI: 17.8 ± 29.0% vs. 11.3 ± 9.7%; 3RI: 14.7 ± 12.2% vs. 6.9 ± 7.3%, respectively). One-way ANCOVA revealed that FR was significantly lower in women than in men at all RIs ($F = 3.53$–16.0; $p = 0.001$–0.05) indicating that 1RM bench press and relative strength did not influence power FR in men and women.

Table 4. Kinetic and kinematic bench press data for the high and low 1RM groups.*

	Average power (W)			Average velocity ($m \cdot s^{-1}$)		
	1RI	2RI	3RI	1RI	2RI	3RI
High 1RM						
Set 1	370.7 ± 79.4†	363.4 ± 87.2†	374.1 ± 104.4†	0.35 ± 0.06	0.34 ± 0.07†	0.35 ± 0.09
Set 2	272.7 ± 58.3†‡	316.9 ± 70.1†‡	329.1 ± 79.4†‡	0.26 ± 0.05‡	0.30 ± 0.06‡	0.31 ± 0.06‡
Set 3	244.5 ± 64.7†‡§	283.7 ± 80.3†‡§	297.0 ± 69.5†‡§	0.23 ± 0.05‡§	0.27 ± 0.06‡§	0.28 ± 0.06‡§
Low 1RM						
Set 1	240.5 ± 34.9†	252.4 ± 45.4†	239.0 ± 31.8†	0.42 ± 0.10	0.44 ± 0.11†	0.42 ± 0.10
Set 2	172.6 ± 50.7†‡	216.8 ± 63.3†‡	212.0 ± 51.6†‡	0.30 ± 0.13‡	0.38 ± 0.15‡	0.37 ± 0.13‡
Set 3	147.2 ± 43.2†‡§	187.5 ± 72.5†‡§	200.2 ± 65.1†‡	0.26 ± 0.11‡§	0.33 ± 0.16‡§	0.35 ± 0.15‡

*RI = rest interval; RM = repetition maximum.
†Indicates $p \leq 0.05$ between groups.
‡Indicates $p \leq 0.05$ from set 1.
§Indicates $p \leq 0.05$ from set 2.

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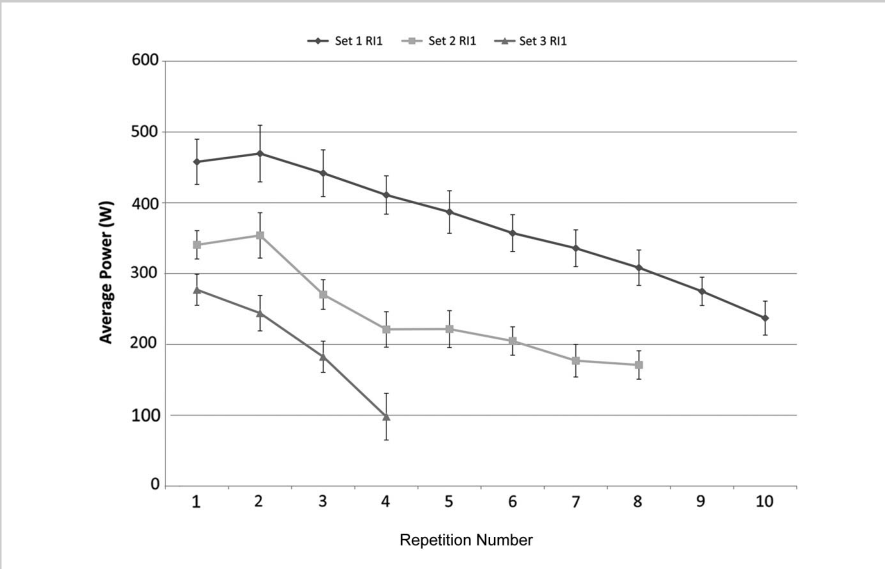

Figure 2. Representative average power obtained during the 1 rest interval (RI) protocol in the high 1-repetition maximum group. Average power (watts) for all 3 sets is depicted. Absent data in sets 2 and 3 indicate a failure of subjects to reach 10 repetitions. Data depicted are mean ± *SEM*.

For average velocity, significant main effects were observed in 1RI ($F[2,19] = 57.8$, $p < 0.001$), 2RI ($F[2,19] = 16.6$, $p < 0.001$), and 3RI ($F[2,19] = 10.6$, $p = 0.001$) where reductions were seen with each set in succession in men during 1RI and 3RI and women during 1RI and 2RI. During 2RI in men, sets 2 and 3 were significantly lower than set 1. During 3RI in women, set 3 was lower than sets 1 and 2. A significant interaction was only observed during 2RI ($F[2,19] = 4.3$, $p = 0.029$) where the rate of decline was significantly lower in women than men. One-way ANOVA revealed that average velocity values in men and women were similar across all sets and RIs. One-repetition maximum bench press correlated significantly with average power across all RIs ($r = 0.789–0.921$). In addition, average velocity significantly correlated with total number of repetitions performed for all sets ($r = 0.330–0.688$).

Bench press repetition data are presented in Table 3 for the second cohort of subjects. Significant main effects were observed during 1RI ($F[2,20] = 121.2$, $P < 0.001$), 2RI ($F[2,20] = 33.3$, $p < 0.001$), and 3RI ($F[2,20] = 22.5$, $p < 0.001$) where repetition numbers decreased during sets 2 and 3 in both groups. A significant interaction ($F[2,20] = 4.6$, $p = 0.02$) was only observed during 1RI where the number of repetitions performed during set 2 was significantly higher in the Low 1RM group. Total repetitions performed over 3 sets were significantly higher in the Low 1RM group during 1RI and 2RI. Significant negative correlations were observed between 1RM bench press and total number of repetitions completed for 1RI and 2RI ($r = -0.558$ and -0.490, respectively).

Bench press kinetic and kinematic data are presented in Table 4 and Figure 2. For average power, significant main effects were observed in 1RI ($F[2,20] = 101.8$, $p < 0.001$), 2RI ($F[2,20] = 37.7$, $p < 0.001$), and 3RI ($F[2,20] = 12.8$, $p < 0.001$) where reductions were seen with each set in succession with the exception of set 3 in the Low 1RM group during 3RI. No significant interactions were observed indicating a similar pattern of decline between the High and Low 1RM groups. One-way ANOVA revealed that all average power values were significantly higher in the High 1RM group than in the Low 1RM group. For average velocity, significant main effects were observed in 1RI ($F[2,20] = 165.6$, $p < 0.001$), 2RI ($F[2,20] = 28.2$, $p < 0.001$), and 3RI ($F[2,20] = 15.6$, $p < 0.001$) where reductions were seen with each set in succession with the exception of set 3 in the Low 1RM group during 3RI. No significant interactions were observed indicating a similar pattern of decline between the High and Low 1RM groups. One-way ANOVA revealed that average velocity in set 1 during 2RI was significantly higher in the Low 1RM group than in the High 1RM group with no other significant differences observed. No significant differences between groups were observed for average velocity and power FRs during 1RI (Low 1RM group = 38.9 ± 6.6%; High 1RM group = 34.2 ± 10.0%), 2RI (Low 1RM group = 27.0 ± 20.4%; High 1RM group = 22.2 ± 7.8%), or 3RI (Low 1RM group = 18.1 ± 15.4%; High 1RM group = 19.5 ± 13.0%). One-repetition maximum bench press correlated significantly with average power across all RIs ($r = 0.571–0.749$) and was significantly negatively correlated with average velocity ($r = -0.373$ to -0.426) during most sets.

Discussion

The salient finding of this study was that manipulation of RI lengths during resistance exercise produces different performance effects in subjects with great disparity of maximal strength. Total repetitions performed during 3 sets of the bench press were significantly higher in women than in men during all RIs and significantly higher in the Low 1RM group than in the High 1RM group during 1RI and 2RI. The results of ANCOVA indicated that maximal strength significantly influenced total repetitions performed (independent of gender) but not power FRs in all RIs. Significant negative

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correlations were observed between 1RM bench press and total number of repetitions completed over 3 sets. In addition, women demonstrated a lower FR when examining bar velocity and power per set. This study supports the findings of previous research by demonstrating a continuum of acute resistance exercise responses where repetition performance, bar velocity, and power are maintained to the highest degree with 3-minute RI but compromised to the largest extent with 1-minute RI.

The length of RIs dictates the magnitude of recovery that takes places in between sets and exercises. Replenishment of the ATP-CP system, buffering of H^+ from energy metabolism, and removal of lactate occur during the recovery period. Within 20 seconds, approximately 50% of ATP and CP are restored, and approximately 85% is restored within 3 minutes if recovery is provided (27). Lactate clearance may require in excess of 4–10 minutes during active recovery (16). Shortening RIs limits the magnitude of recovery and the subject performs subsequent sets in a prefatigued state thereby compounding the effect and increasing FR. This may increase the reliance on slow-twitch muscle fibers (as fast-twitch fibers are less oxidative, more fatigable, and require longer recovery periods) resulting in altered recruitment patterns and reduced force production (40). These physiological phenomena play critical roles when examining acute resistance exercise performance. Reduced loading capacity with short RIs results in a slower rate of strength increase (7,14,29,33), which is the rationale for the current recommendation of at least 2–3 minutes of rest between sets of multiple-joint structural exercises for progression during intermediate and advanced strength training (30).

A unique finding of this study was that gender differences were observed for the bench press protocols when 1-, 2-, and 3-minute RIs were used. This study demonstrated that women have a greater capacity to perform more repetitions despite the RI length than do men. Further analysis revealed that strength differences between genders accounted for the majority of the performance differences observed. Previous studies have shown women have lower decrements in force output and faster recovery capacity during moderate-to-high-intensity exercise than men (6,25). Women have been shown to have reduced ATP depletion (8), faster ATP recovery (8), lower blood lactate (12,25), lower epinephrine (12), lower respiratory exchange ratio (28), and lower glycogen breakdown in type 1 fibers (8) in response to maximal sprint and resistance exercise. Häkkinen (13) showed female athletes had a faster recovery of force production 1 hour after a heavy-resistance exercise session than did male athletes. Judge and Burke (19) reported women recovered faster from a bench press protocol than men. Sayers and Clarkson (35) reported that women recovered more force 132 hours after an eccentric exercise protocol than did men. After matching men and women for maximal isometric strength of the adductor pollicis muscle, Fulco et al. (10) reported that women displayed a reduced rate of force loss after a fatiguing protocol, greater endurance time to exhaustion, and a faster recovery of force 1 minute after the protocol. Willardson et al. (44,45) showed that during a squat protocol with 1-minute RIs, men needed a 15% reduction in load for each set in succession (to maintain repetition number), whereas women needed only a 10% reduction. Thus, women appear to experience less fatigue and have superior recovery ability during short-term RIs compared with men. These data may have important ramifications for resistance exercise RI prescription in women.

Few studies have investigated RI manipulation on acute resistance exercise performance in women. Hill-Haas et al. (14) showed that 5 weeks of resistance training with 2–5 sets of 15–20 repetitions with 20-second RIs in between sets resulted in greater repeated-sprint performance than training with 80-second RIs (12.5 vs. 5.4%); however, training with 80-second RIs produced greater increases in muscle strength (45.9 vs. 19.6%). Willardson et al. (45) examined load reductions needed in women to maintain repetition performance for the bench press, squat, and lat pulldown exercises with 10RM loads using 1-minute RIs. They reported that 10% reductions were needed for the squat and lat pulldown during the second and third sets and between 10 and 15% reductions were needed for the bench press during the second and third sets. The results of this study indicated that women were able to maintain repetition performance during the second set of the 1RI protocol but showed significant reductions during the third set. One difference between studies is 75% of 1RM was used in this study, whereas Willardson et al. (45) used a 10RM load, which could account for their repetition maintenance observed during set 2. The women in this study only showed a reduction during set 3 in 2RI and were able to maintain repetition performance throughout the 3 sets during 3RI thereby supporting research examining other high-intensity exercise modalities where women showed less fatigability (2,25). These data demonstrate that women have greater fatigue resistance and recovery ability compared with men.

One potential limitation to the gender comparison literature base is the inability to equate resistance trained men and women based on absolute peak power or strength measures (2). Women in this study had significantly less body mass, 1RM bench press, and relative strength than did men. The inherent difficulty in matching trained men and women for absolute maximal strength and power was seen in this study. For example, the highest 1RM bench press in the group of women was 45.4 kg, whereas the lowest 1RM bench press in the group of men was 77.7 kg yielding a difference of approximately 32.3 kg between the strongest woman and weakest man in this study. The group means were more substantial (i.e., ~76-kg difference between women and men in the first cohort). Results of the ANCOVA indicated that maximal strength appeared to be a more influential variable than gender per se when comparing repetition performance between men and women. In lieu

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of this challenge and to further investigate the relationship between maximal strength and acute resistance exercise performance, we recruited a larger cohort of men with substantial maximal strength disparity.

Strength disparity among the male participants played a role during acute resistance exercise performance in this study. Total repetitions performed over 3 sets were significantly higher in the Low 1RM group during 1RI and 2RI. In addition, significant negative correlations were observed between 1RM bench press and total number of repetitions completed for 1RI and 2RI. These data indicate that stronger men have greater fatigability or attenuated recovery capacity in response to short (1- and 2-minute) RI lengths compared with those men with a lower 1RM bench press. These results extend our previous findings showing that children and adolescents (with considerably less 1RM strength than adults) had superior acute bench press performance (determined by total repetition number over 3 sets) compared with adult men during short RI lengths (9). Although it was beyond the scope of this investigation to identify specific mechanisms involved in performance variance, it could be speculated that physiological factors that contribute to superior maximal strength enhancement (i.e., neural recruitment patterns, firing rate, and synchronization, preponderance of fast-twitch muscle fibers, ATP-CP stores and depletion-repletion rates, muscle architecture, and increased muscle cross-sectional area) coupled with potential limitations in capillary and mitochondrial density, anaerobic enzyme activity, and buffer capacity may contribute to reduced high-intensity local muscle endurance and recovery seen in between bouts of high-intensity resistance exercise.

The results of this study support previous research demonstrating a continuum of performance reductions with short RI lengths (20,31). Repetition reductions were greatest during 1RI and least during 3RI in all the subjects in this study. Ratamess et al. (31) showed that volume load significantly decreased with each set in succession over 5 sets of the bench press when 30-second and 1-minute RIs were used; and that lifting performance was maintained over 2 sets for 2-minute RIs, 3 sets for 3-minute RIs, and 4 sets for 5-minute RIs with subsequent reductions taking place for the remaining sets. Other studies have shown volume load is greater with 5- vs. 3- vs. 1-minute RIs (34,36). Kraemer (20) showed that subjects were able to perform 10 repetitions with 10RM loads for 3 sets when 3-minute RIs for the leg press and bench press were used. However, when RIs were reduced to 1 minute, 10, 8, and 7 repetitions were performed, respectively. Richmond and Godard (32) showed that total work for 8–12 repetitions was maintained over 2 sets with 75% of 1RM for the bench press when 3- and 5-minute RIs were used. However, performance declined with 1-minute RIs. Willardson and Burkett (40) reported that volume was highest when a 5-minute RI was used, followed by 2- and 1-minute RIs when performing 4 sets of the squat and bench press with 8RM loading. They also showed that when performing 5 sets of 15 repetitions, neither 30-second, 1-, or 2-minute RIs were sufficient to maintain performance (42), and 3-minute RI was more effective (i.e., higher repetitions performed) than 2- and 1-minute RIs for maintaining bench press performance over 5 sets with 80% of 1RM (41).

Critical to this investigation was the measurement of velocity and power during each repetition. Velocity and power embody the quality of each repetition that needs to be high during optimal strength and power training (30). Changes in power and velocity may occur independently of the number of repetitions completed. Thus, assessment of bar velocity and power provides additional information regarding components of fitness susceptible to fatigue and RI length manipulation. A continuum of responses was shown where average velocity and power were reduced the most during 1RI and the least during 3RI in this study. In addition, Figures 1 and 2 depict power output declines shown for each repetition throughout the 3 sets during 1RI. Few studies have addressed the kinetics and kinematics of each repetition of the bench press under RI manipulation. Abdessemed et al. (1) studied 10 sets of 6 repetitions of the bench press using 70% of 1RM with 1-, 3-, or 5-minute RIs and reported significant reductions in average power per set (27% between sets 4 and 10) when 1-minute RIs were used but power performance was maintained with 3- and 5-minute RIs. These data, coupled with the data from this study, indicate that power and velocity reductions are most prominent when short RIs are used and support resistance training recommendations of long RI lengths for power training to preserve the quality of each repetition (30).

Power FR was 22.6% (1RI), 11.3% (2RI), and 6.9% (3RI) in women and 34.8% (1RI), 17.8% (2RI), and 14.7% (3RI) in men, respectively, with 1RI and 3RI protocols significantly different between groups. These data demonstrated that women had less fatigability and superior recovery ability in between sets compared with men. Gender differences were observed as ANCOVA analysis revealed no effects of maximum strength on power FR. In the cohort of men, power FR was 38.9% (1RI), 27.0% (2RI), and 18.1% (3RI) in the Low 1RM group and 34.2% (1RI), 22.2% (2RI), and 19.5% (3RI) in the High 1RM group, respectively, with no significant differences observed between groups. The unique finding was that the level of maximal strength did not affect power FRs despite the RI length in these 2 groups of men. Although 1RM bench press strength was significantly related to repetition performance, it was not related to power and velocity FRs in either cohort of subjects. Interestingly, the Low 1RM group displayed power FRs larger than our female cohort suggesting that the maximal strength disparity may have been too large to establish a similar response.

In summary, manipulation of RI lengths during the bench press protocols produced different performance effects in the subjects with great disparity of maximal strength. Total

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bench press repetitions performed were significantly higher in women than in men during all RIs and significantly higher in the Low 1RM group than in the High 1RM group during 1RI and 2RI. Significant negative correlations were observed between 1RM bench press and total number of repetitions completed over 3 sets. In addition, women demonstrated lower velocity and power FRs than men did. These data indicate that women have less fatigability and superior recovery capacity in between sets of resistance exercise compared with men and men with higher levels of maximal strength may be more susceptible to reduced repetition performance using short (1- and 2-minute) RIs. These results suggest that maximal strength disparity could be a critical variable of influence regarding total numbers of repetitions performed despite RI length. Strength and conditioning practitioners may apply these findings by modifying RI length prescription among athletes with disparity in muscle strength. In particular, it appears women may not need as much rest in between sets to perform a comparable amount of repetitions in comparison with men.

Practical Applications

Often RI length during resistance exercise is prescribed based solely on the individual's training goals. For example, longer (at least 2–3 minute) RI lengths for multiple-joint structural resistance exercises have been recommended for strength, power, and hypertrophy training whereas shorter (≤1–2 minutes) RI lengths have been recommended for muscle endurance and hypertrophy training (30). The results of this investigation indicate that acute resistance exercise performance varies among individuals with disparity in maximal strength. Women performed a larger number of repetitions using all RIs and men in the Low 1RM group performed significantly more repetitions during 1RI and 2RI compared with men in the High 1RM group. For example, women performed as many repetitions during 1RI as men did during 3RI. If one views acute resistance exercise performance as the major stimulus for subsequent training adaptations, then the results of this study indicate that individuals with lower levels of maximal strength may not require as much rest in between sets as those with larger levels of maximal strength when repetition performance is compared. Clearly, the quality of each repetition (i.e., velocity and power) was superior with 3-minute RIs, so further research is warranted investigating the potential different effects of total repetitions completed vs. the quality of each repetition in eliciting positive training adaptations. These issues notwithstanding, the results of this study indicate that RI length prescription during the bench press may be dependent, in part, on the individual's gender (for FR) and level of maximal strength (for repetition performance).

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