Physical Performance and Electromyographic Responses to an Acute Bout of Paired Set Strength Training Versus Traditional Strength Training

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Abstract

Robbins, DW, Young, WB, Behm, DG, Payne, WR, and Klimstra, MD. Physical performance and electromyographic responses to an acute bout of paired set strength training versus traditional strength training. *J Strength Cond Res* 24(5): 1237–1245, 2010—The objective of this study was to investigate the acute effects of performing paired set (PS) vs. traditional set (TS) training over 3 consecutive sets on volume load (VL) and electromyographic (EMG) activity of the pectoralis major, anterior deltoid, latissimus dorsi, and trapezius muscles. Following a familiarization session 16 trained males performed 2 testing protocols using 4 repetition maximum loads: TS (3 sets of bench pull [Bpull] followed by 3 sets of bench press [Bpress] performed in approximately 20 minutes) or PS (3 sets of Bpull and 3 sets of Bpress performed in an alternating manner in approximately 10 minutes). Bpull and Bpress VL decreased significantly from set 1 to set 2 and from set 2 to set 3 under both conditions. There was no difference between VL per set, or over the sessions, between the 2 conditions. PS was determined to be more efficient (VL/time) as compared to TS. EMG activity of the 4 monitored muscles was not different for the 2 conditions or within each condition over the 3 sets. However, there was a significant within-set response in EMG activity in the Bpress exercise. The data suggest that a 4-minute rest interval between sets may not be adequate to maintain VL using either protocol. The data further suggest that PS training may be as effective as TS training in terms of VL maintenance and more effective in terms of efficiency. The comparison of EMG activity between the PS and TS protocols suggests that the level of neuromuscular fatigue does not differ under the 2 conditions. PS training would appear to be an effective method of exercise with respect to VL maintenance and efficiency.

Key Words paired set, bench press, bench pull, complex training

Introduction

Resistance training is an effective method for developing muscular strength (6). Furthermore, resistance training modalities that aim to enhance musculoskeletal conditioning have been associated with improved health and a decrease in the risk of chronic disease and disability (24). Athletes and trainers face a number of challenges in preparation for competition, and the general population faces challenges with respect to the maintenance of health and wellness. Time is a constraint, and one such challenge, for athletes and the general population. Resistance training protocols that save time without compromising efficacy, or increase efficiency, could be advantageous to a variety of athletes and the general population. A number of resistance training schemes aimed at efficiency have been devised (2,18,21). One such "efficient" training scheme, which attempts to manipulate local fatigue, may be referred to as "paired set training." For the purposes of this research, a paired set (PS) refers to the coupling of exercises targeting different muscle groups, performed coincidentally, in an alternating manner. Among a variety of possible combinations are paired sets that couple agonist and antagonist muscle groups. Within agonist/antagonist paired sets are a number of possible combinations, including pairing 2 heavy traditional weight training exercises (e.g., bench pull [Bpull] and bench press [Bpress]). Dissimilar exercises are performed in an alternating fashion with rest intervals between each set.

Sufficient rest intervals (RI) between sets of resistance exercise are necessary to allow the exercised muscles to

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resynthesize intramuscular phosphocreatine and adenosine triphosphate and to remove metabolites detrimental to work production (5). It has been suggested that a 3–5-minute RI between resistance training sets is adequate to recover and perform a similar amount of work in successive sets (8–11,15). During the 3–5-minute RI necessary for the initially targeted muscle group to recover, a participant performing PS exercises a different muscle group (i.e., one antagonistic to the muscle group initially exercised). Theoretically, the initially targeted muscle group is able to recover during its RI. The muscle group targeted in the second phase of the paired set is able to recover during a similar RI, during which time the initially targeted muscle group performs another set. The exercises are performed in this alternating manner over consecutive sets. Assuming recovery is possible over multiple sets, by concurrently training 2 muscle groups in such a manner, more work is performed per unit of time.

Baker and Newton (1) investigated a pairing of agonist and antagonist exercises. They reported that power output (PO) in the bench press throw (BPT) was significantly greater when preceded by a set of bench pulls, compared to PO in a set of BPTs with no intervention. The researchers suggested that the augmentation of power output may have been a result of enhanced reciprocal inhibition of the antagonist musculature–that is, the loading of the agonist altered the braking phase of the triphasic pattern of the antagonist musculature during the agonist power exercise. However, the researchers did not incorporate a mechanistic evaluation (i.e., electromyography [EMG]) into the research to support this hypothesis. The findings of Baker and Newton (1) are supported by Burke et al (3), who investigated a set of isokinetic agonist/antagonist movements (seated bench press and seated bench pull) performed as 1 repetition–that is, there was no RI between the agonist and antagonist movements. They found a significant increase in torque production in the agonist exercise when the loads for both the agonist and antagonist activities were low, allowing for fast contraction speeds. This was not the case when either contraction was performed at a slow contraction speed or when the antagonist contraction was isometric. The researchers hypothesized that stretch reflex and stored elastic energy within the agonist muscle group may have been responsible for the additional force observed when fast contractions were coupled with fast contractions. However, the investigators did not incorporate a mechanistic component (i.e., EMG) into the research to support this hypothesis. Unlike the 2 previously discussed studies, Maynard and Ebben (14) found a decrease in peak torque, rate to peak torque, and peak power production in the agonist musculature when the antagonist muscle group were prefatigued. Also unlike the 2 previously discussed studies, the researchers investigated the lower body, using isokinetic knee flexion and extension. The researchers measured the EMG activity of the agonist and antagonist musculature and suggested that perhaps the observed increase in EMG activity of the antagonist (co-contraction) may have been responsible for the attenuation in performance measures. It is unclear if there is a differential response in the upper body as compared to the lower body. It may be that the level of coactivation is greater in the knee flexors and extensors as compared to that seen in the chest and back muscle groups. A greater level of coactivation in the antagonist musculature may manifest itself as fatigue and affect that muscle group adversely when acting as an agonist.

Commonly, athletes in a resistance training setting perform multiple sets of isotonic exercises. It should be noted that of the 3 studies discussed earlier, only Baker and Newton (1) investigated isotonic exercises. However, their study did not involve multiple sets. To date, there have been no scientific studies reported that have examined the mechanism underlying, or responses to, PS in which agonist/antagonist pairings of high resistance isotonic exercises are investigated over consecutive sets. It is possible that this method of training could be a time-efficient method for developing strength without compromising efficacy. The purpose of this study was to investigate the efficacy (VL maintenance) and efficiency (VL/time) of agonist/antagonist paired sets involving 2 heavy resistance exercises.

Methods

Experimental Approach to the Problem

A within-subject randomized, counterbalanced comparison was used to investigate whether significant differences in VL existed between PS and TS over 3 sets. Because of the familiarity of movement and widespread use as a means to develop strength, Bpull and Bpress were chosen as the pulling and pushing exercises, respectively. A 4 repetition maximum (4RM) was prescribed for all sets in both protocols and was performed to failure, which was considered to have been reached when another repetition using proper technique could not be performed (25). The completed number of proper repetitions was recorded for each set and used to calculate VL for each set of both exercises. High-intensity loads (e.g., 4RM) performed over repeated trials have been recommended with respect to strength development (2,27). The TS protocol was designed to reflect the common practice of stressing 1 muscle group via multiple sets before moving on to another muscle group. The PS protocol was designed to stress the same musculature as that stressed under the TS condition but in less time. The total time required to complete the testing sessions, and the order in which the exercises were performed, differed between the 2 protocols (PS and TS). In both protocols, a 4-minute RI was instituted between similar exercise sets. The TS protocol involved performing 3 sets of Bpull followed by 3 sets of Bpress, with a 4-minute RI between each set (Figure 1). The PS protocol performed the same exercises (Bpull and Bpress) but in an alternating manner. The RI between like exercise sets was similar to that used in the TS protocol (4 minutes) and the RI between unlike exercise sets was 2 minutes.

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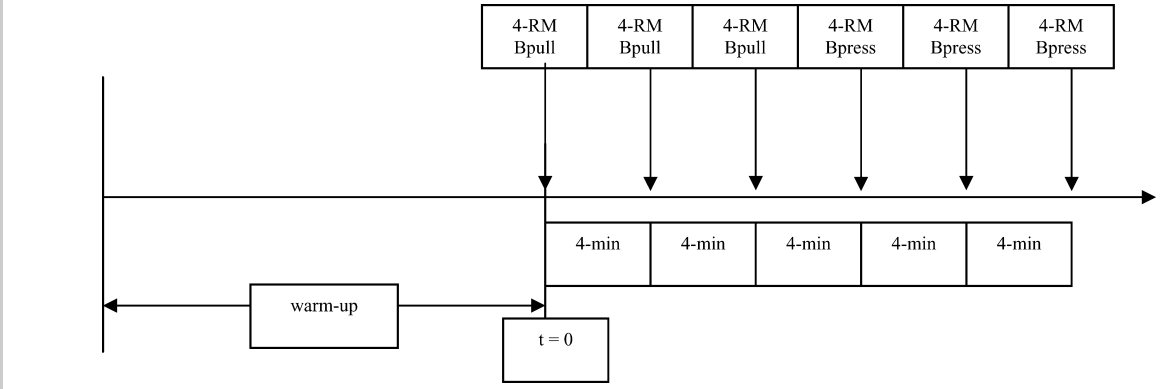


Figure 1. Schematic representation of traditional set (TS) protocol. 4RM = 4 repetition maximum; Bpull = bench pull; Bpress = bench press.

The PS protocol required approximately half the time to complete, as compared to the TS protocol. The second exercise set (Bpress) was performed in such a manner that the midpoint of the execution of the second exercise set was 2 minutes after the beginning of the execution of the first exercise set (Figure 2). To assist in the explanation of any observed differences in VL, EMG responses of 4 muscles (pectoralis major, anterior deltoid, latissimus dorsi, and middle portion of the trapezius) were monitored in every set of both exercises. Specifically, mean amplitude of the root mean square (RMS) and the median frequency (MDF) were collected. Fatigue-induced changes in RMS (increases) and MDF (decreases) EMG signals can provide an indication of general motor unit activation and signal frequency, respectively (23).

Subjects

Sixteen trained males with at least 1 year's training experience with pushing and pulling resistance exercises volunteered to participate in the study. Participants were generally collegiate athletes with several years of training experience, and testing occurred during the off season (the month of June). The participants' descriptive data are displayed in Table 1. The study was approved by the University Human Ethics Committee Review. Prior to the investigation, all subjects were briefed on the testing protocols, experimental risks, equipment, and nature of the study prior to signing an informed consent document. All participants were asked to refrain from any upper-body training in the 48 hours prior to each training session.

Procedures

VL was measured during all sets of both protocols by multiplying the load by the number of correct repetitions achieved. Participants underwent a familiarization session to determine their 4RM for the bench pull and bench press and were instructed on exercise technique. To determine 4RM, participants performed a set of 5–10 repetitions using 30–50% of expected maximum, followed 1 minute later by a set of 3–5

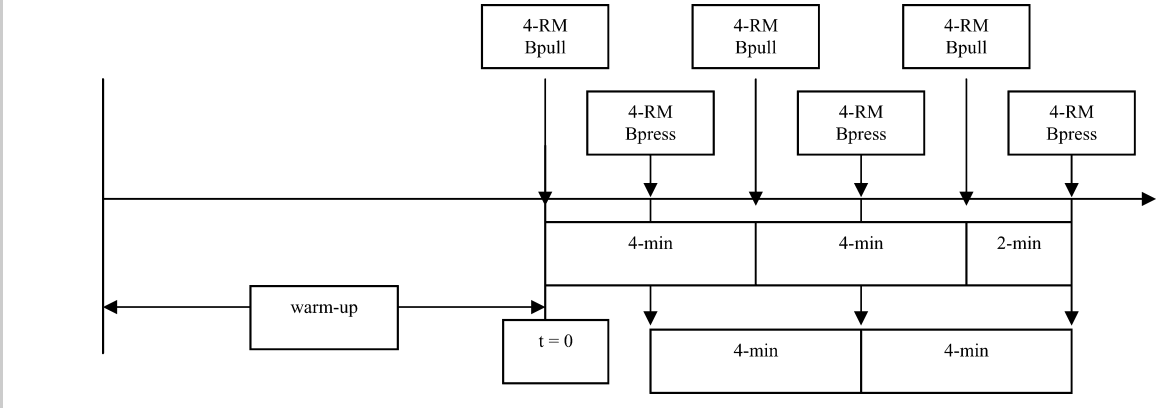


Figure 2. Schematic representation of paired set (PS) protocol. 4RM = 4 repetition maximum; Bpull = bench pull; Bpress: bench press.

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Table 1. Description of subjects.

	Age (y)	Height (cm)	Mass (kg)	4RM Bpull (kg)	4RM Bpress (kg)
Mean	23.8	184.2	87.5	77.5	90.0
SD	5.2	8.5	16.0	12.3	20.2

4RM Bpull = 4 repetition maximum bench pull; 4RM Bpress = 4 repetition maximum bench press.

repetitions using 50–70% of expected maximum. After a 2-minute RI, 4RM attempts were made with approximately 2-minute RIs between attempts. If an attempt was successful using correct technique, further attempts were made using increasing increments of weight. The last successful attempt was recorded as the participant's 4RM in that lift. This procedure was adopted from Stone and O'Bryant (22) with 1 change–rather than 1-minute RIs between attempts, 2-minute RIs were used. The familiarization session was performed 1 week prior to the first testing session, which was performed 1 week prior to the second testing session. All testing was performed at the same time of day and a standardized warm-up (specific to the testing protocol) was performed in all 3 sessions. Prior to testing, participants performed progressive submaximal exercise. Specifically, participants performed 3 sets of lifts similar to the 2 lifts being tested at 60, 80 and 90% of 4RM (calculated from the previously determined 4RM). A 4-minute RI was provided between like exercises. Prior to the TS testing session, the warm-up sets were executed in a successive manner–that is, 3 sets of the first exercise followed by 3 sets of the second exercise. Prior to the PS testing session, the warm-up sets were performed in an alternating manner.

All sets of both Bpull and Bpress were performed to failure using previously determined 4RM loads. The bench pull tests were performed on an adjustable high bench (Apex B45 adjustable flat bench), positioned on Step1005 platforms. Participants were instructed to lie prone on the bench and grasp an Olympic bar placed on the floor with a pronated grip. The bench was adjusted so that the participant's arms were straight in this position. A repetition was deemed to have been completed by moving the bar from the floor until it touched the bottom of the bench. Between repetitions the bar was motionless on the floor for 1–2 seconds. Hand placement and tempo were self-determined. Participants were instructed to keep their head, upper body, and legs flat to the bench. When performing the bench press, participants lay supine on a flat bench with feet flat on floor and head, shoulders, and buttocks flat to the bench. A repetition was deemed to have been completed when the bar was moved from the chest to a position of full elbow extension. Between repetitions the bar was momentarily held motionless on the chest. Hand placement and tempo were self-determined.

Prior to the commencement of the 3 testing sessions, a reliability study involving 10 of the subjects who later participated in the study determined the test-retest (separated by 1 week) intraclass correlation coefficients (ICC) and percent total error (%TE).

Electromyography. EMG data were collected using surface electrodes (Delsys DE-2.1 sensors, Boston, MA, USA), with an interelectrode distance of 1 cm using an active differential preamplifier configuration (Delsys DE 2.1). These electrodes were connected to an analog to digital converter (Bagnoli Myomonitor III wireless system, Delsys Inc., Boston, MA, USA) and acquired with the assistance of proprietary software (EMGworks Acquisition 3.5, Delsys Inc., Boston, MA, USA). EMG signals were amplified by 1,000 with a frequency bandpass of 20–450 Hz (common mode rejection ratio of 92 dB) and recorded at 1,000 Hz (Bagnoli Myomonitor III wireless system). The mean amplitude of the RMS and the MDF analysis was performed using custom-written software (National Instruments LabVIEW 8). Briefly, the RMS is the square root of the average power of the EMG signal for a given period of time and was measured according to Equation 1.

$$x_{\mathrm{rms}} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} [f(t)]^2 \, \mathrm{dt}} \qquad (1)$$

where x_{rms} is the computed EMG_{RMS} value. T_1 and T_2 are the limits of the chosen time interval, and *f(t)* is the continuous unprocessed EMG signal. The averaging window for RMS

Table 2. Percent changes in volume load (VL) from Set 1 to Set 2 and Set 2 to Set 3 for bench pull (Bpull) and bench press (Bpress) during paired set (PS) and traditional set (TS) protocols. Mean (*SD*) ($n = 16$).

	Set 1–Set 2		Set 2–Set 3	
Variable	PS	TS	PS	TS
Bpull VL	9.75% (±19.25)	−13.36% (±17.48)	−15.51% (±24.59)	−10.42% (±19.21)
Bpress VL	−8.25% (±31.10)	−11.56 % (±22.33)	−29.78% (±21.41)	−12.41% (±25.28)

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was 100 ms, and all reported values are the mean RMS over a predetermined sampling window from the onset to the end of each contraction. The MDF is defined as the frequency that divides the power density spectrum in 2 equal regions. Thus, the MDF was calculated by finding the frequency that halved the integrated power spectrum of the EMG signal over a predetermined sampling window from the onset to the end of each contraction. Data were collected throughout the entire set for all sets. EMG data collected from the entire (concentric and eccentric) first contraction were compared to EMG data of the entire final contraction.

The EMG signal was acquired from pectoralis major, anterior deltoid, latissimus dorsi, and trapezius muscles located on the right side of each participant using surface electrodes with an interelectrode distance of 1 cm. The pectoralis major electrode was placed midpoint between the acromion process and the xiphoid process. The anterior deltoid electrode was placed on the midbelly, 3–4 cm beneath the anterior margin of the acromion process. The latissimus dorsi electrode was placed lateral to the inferior angle of the scapula. The trapezius electrode was placed midway between the scapula spine and spinous process at same level. A ground electrode (flexible 1-cm disposable Ag-AgCl surface EMG electrodes, Thought Technologies Ltd, Montreal, PQ, Canada) was placed on the right elbow. Prior to electrode placement, the area of skin was thoroughly prepared with abrasive paper and isopropyl alcohol swabs to improve conductivity of the EMG signal.

Traditional Set Protocol. Prior to testing, participants performed the aforementioned standardized warm-up. Testing commenced following a 4-minute RI. Three sets of Bpull were followed by 3 sets of Bpress, with a 4-minute RI between each set. All sets were performed to failure using a previously determined 4RM load. The load and number of correct repetitions completed were recorded for each set of both exercises. All sets of Bpress were spotted by an experienced lifter to ensure volitional fatigue was achieved safely and with the confidence of the subject. The testing session took approximately 20 minutes to complete. During the RI between sets, participants engaged in passive rest and were given verbal encouragement.

Paired Set Protocol. Prior to testing, participants performed a warm-up similar to that performed in the traditional set protocol, except that the submaximal exercises were performed in an alternating manner rather than successively. Similar testing procedures to those used in the traditional set protocol were implemented. However, the 3 sets of Bpull were performed in an alternating manner with the 3 sets of Bpress. Also, although the RI between like sets was 4 minutes, the RIs between work performed were less. At the midpoint of the RI between like sets, the other exercise (i.e., antagonistic) was executed. The RI between work performed was approximately 2 minutes. Therefore, the

Table 3. Total volume load (VL) and effect size (ES) per set and session for bench pull (Bpull) and bench press (Bpress) during paired set (PS) and traditional set (TS) protocols. Mean (*SD*) ($n = 16$).

Variable	Set 1			Set 2			Set 3			Session		
	PS	TS	ES	PS	TS	ES	PS	TS	ES	PS	TS	ES
Bpull VL (kg)	397.46 (±174.61)	420.71 (±180.39)	0.13	361.17 (±166.98)	363.01 (±151.21)	0.01	301.92 (±152.71)	321.77 (±135.69)	0.14	1060.56 (±467.34)	1105.49 (±448.38)	0.10
Bpress VL (kg)	422.83 (±213.63)	434.17 (±292.66)	0.04	365.99 (±164.82)	362.87 (±216.57)	0.02	250.75 (±123.79)	310.43 (±172.62)	0.40	1039.58 (±485.16)	1107.47 (±660.25)	0.12

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Table 4. Efficiency (volume load/time) calculations for session bench pull (Bpull) and session bench press (Bpress) during paired set (PS) and traditional set (TS) protocols. ($n = 16$).

	PS			TS		
Variable	VL (kg)	Time (min)*	Efficiency (kg/min)	VL (kg)	Time (min)*	Efficiency (kg/min)
Bpull	1060.56	10	106.06	1105.49	20	55.27
Bpress	1039.58	10	103.96	1107.47	20	55.37

*The final set was initiated at 10 minutes (PS) or 20 minutes (TS) and therefore the total time to complete the sessions varied slightly (e.g., if 12 seconds were required to complete the final set in the PS protocol, total time to complete the session would be 10.2 minutes).

testing session was completed in approximately 10 minutes. During the RI between sets, participants engaged in passive rest and were given verbal encouragement.

Statistical Analyses

The set and session totals of VL for Bpull and Bpress in both testing protocols were calculated. These data were analyzed using a 2-way analysis of variance (ANOVA) (2×3) with repeated-measures and paired *t*-tests to determine whether there were significant main effects or interactions for the type of training (TS and PS) and the sets (1, 2, and 3). Analysis of the data to determine if any significant differences existed between the 2 testing protocols was performed to investigate the influence of PS on the maintenance of VL. EMG data (RMS and MDF) were gathered for the first and last repetition of each set. EMG data were analyzed using a 3-way ANOVA ($2 \times 3 \times 2$) with repeated measures to determine whether there were significant main effects or interactions for the type of training (TS and PS), the sets (1, 2, and 3), and the repetitions (first repetition and last repetition). Efficiency (VL/time) calculations were also made. The level of statistical significance was set at $p \leq 0.05$ for all tests with the exception of the 3-way ANOVA comparing the EMG in PS to TS and within each condition, which was adjusted using the Bonferroni technique and set at $p \leq 0.001$. All statistical tests used SPSS version 16 (Chicago, IL, USA). Effect size calculations were performed on measures of VL (7).

The reliability study determined that ICCs and %TE for average and total VL over 3 sets for Bpull and Bpress ranged between 0.91 (3.9%) and 0.99 (13.4%), respectively. Paired sample *t*-tests revealed no significant ($p < 0.001$) differences between the 2 testing occasions. The test-retest ICC of the EMG measures for the 4 monitored muscles ranged between 0.83 and 0.96.

Results

Independent analysis of testing protocols found both Bpull and Bpress VL decreased significantly from set 1 to set 2 and from set 2 to set 3 in the PS and TS conditions ($p < 0.05$). The

Table 5. Percent changes in electromyographic signal, root mean square (RMS) and median frequency (MDF), from first repetition to final repetition in sets 1, 2 and 3 of the pectoralis major (pec. major), anterior deltoid (ant. delt.) and trapezius muscles for bench press during paired (PS) and traditional set (TS) protocols. Mean (*SD*) ($n = 16$).

	Set 1		Set 2		Set 3	
Variable	PS	TS	PS	TS	PS	TS
RMS: Pec. major	−51.11% (±26.98)	−46.16% (±31.25)	−58.07% (±46.69)	−55.13% (±45.93)	−41.28% (±22.01)	−39.07% (±18.73)
RMS: Ant. delt.	−57.26% (±43.02)	−38.67% (±40.44)	−58.83% (±44.16)	−39.61% (±22.68)	−41.91% (±38.32)	−33.56% (±20.37)
RMS: Trapezius	−33.06% (±30.43)	−13.89% (±28.91)	−20.94% (±30.31)	−23.19% (±26.20)	−24.60% (±21.07)	−22.19% (±30.91)
MDF: Pec. major	16.35% (±8.20)	18.31% (±5.95)	13.82% (±7.36)	13.35% (±5.71)	8.74% (±6.98)	8.62% (±4.75)
MDF: Ant. delt.	19.32% (±7.44)	18.54% (±8.45)	18.17% (±8.53)	18.35% (±5.92)	13.27% (±6.47)	10.91% (±8.72)
MDF: Trapezius	12.54% (±14.86)	12.00% (±9.76)	8.52% (±13.15)	13.38% (±11.11)	9.86% (±10.42)	7.64% (±8.85)

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percent changes, from set to set, in Bpull and Bpress are shown in Table 2. However, there was no difference in Bpull or Bpress VL per set, over the 3 sets performed, between the 2 conditions. There was also no difference in session Bpull or Bpress VL under the 2 conditions. VL data and effect sizes for Bpull and Bpress are shown in Table 3. PS was determined to be more efficient. Efficiency calculations are shown in Table 4. There were no EMG activity main effects or interactions for type of training or between sets. There was a main effect for repetitions observed in the pectoralis major, anterior deltoid, and trapezius muscles for both RMS and MDF. Specifically, RMS increased and MDF decreased significantly during the Bpress exercise in each set in both conditions. The within-set percent changes observed during Bpull and Bpress are shown in Table 5.

Discussion

PS training, under designations such as "super sets" or "compound sets," has been prescribed by practitioners as a means of developing strength. It has been suggested by various body-building publications that this type of training is time-efficient without compromising results. In the present study, Bpull and Bpress VL were not different per set, or for the session, under the PS and TS conditions. Efficiency calculations (Table 4) determined PS training to have almost double the efficiency compared to TS training. These findings would seem to support the hypothesis that with respect to PS training efficiency is enhanced because the session time was approximately half with no significant decrease in VL. Comparisons of EMG data across the 2 conditions indicate that the PS protocol had no greater neuromuscular activation deficits than the TS protocol.

Although there were no differences in EMG signal across conditions or from set to set, there were differences from first repetition to final repetition within all sets of Bpress in both conditions in the pectoralis major, anterior deltoid, and trapezius muscles. This was not observed in the latissimus dorsi muscle during Bpress or in any of the 4 monitored muscles during sets of Bpull. This can perhaps be explained by the fiber-type composition of the 4 muscles and the relative involvement of the muscles in the Bpress and Bpull exercises. The percentage of Type 1 (fatigue resistant) fibers in the pectoralis major, anterior deltoid, latissimus dorsi, and trapezius muscles has been reported to be 35, 47, 48 and 44%, respectively (12,20)–that is, among the 4 monitored muscles, the latissimus dorsi is arguably the most fatigue resistant. Furthermore, with respect to the Bpress exercise, it is likely that the latissimus dorsi does not play the major role, whereas, with respect to the Bpull exercise, the latissimus dorsi plays the major role. With respect to the Bpress exercise, the pectoralis major and anterior deltoid are likely the major contributors in this movement.

The contractile response of skeletal muscle is partially determined by its contractile history (13). Because of the nature of PS training, the contractile history of the agonist and antagonist must be considered. Coactivation refers to the concurrent activation of agonist and antagonist muscles (4,16). Unlike the present study, the 2 previous studies that investigated upper body contrast sets (1,3) did so in attempts to augment performance and, as such, utilized different protocols. The coactivation-related mechanisms proposed by the researchers to explain the observed acute performance enhancement are unlikely to have played a role in the present study. Because of the nature of the protocol (i.e., nonballistic-type movements, pauses at the end of the range of motion, and a 2-minute RI between agonist and antagonist exercises) utilized in the present study, and subsequent results, changes in stored elastic energy (3) or the extent of EMG activity (both RMS and MDF) (1) were not a factor.

This study only examined responses of 1 PS (2 exercises) performed over 3 trials (6 sets). Commonly, resistance training sessions targeting multiple muscle groups involve more than 2 exercises and more than 6 sets. Thus, the differences in session VL (Bpull and Bpress) in PS as compared to TS, although not statistically different in the present study, could continue to grow over a longer training session and manifest themselves as significant. Furthermore, it must be acknowledged that the maintenance of a similar acute VL under PS, as compared to TS, does not necessarily yield equivalent, or effective, chronic development of strength over an extended period.

Although VL did not differ between the 2 conditions, VL did decrease from set 1 to set 2 and from set 2 to set 3 in both exercises under both conditions. This would seem to indicate that a 4-minute RI was not adequate for the targeted musculature to recover from local fatigue and maintain the volume of work. Although, to date, there have been no scientific studies reported examining VL maintenance in the Bpull, a number of studies have examined VL maintenance in the Bpress exercise. However, Bpress VL maintenance has not been examined as the second exercise in a training session–that is, following 3 sets of Bpull (TS) or as half of a PS.

The RI necessary to maintain Bpress repetitions would appear to be dependent on the magnitude of the load. Specifically, submaximal (i.e., $<$90% of 1RM) loads performed to failure would seem to require somewhat longer RIs as compared to maximal (i.e., 1RM) loads (8,27). Weir et al (26) found a 1-minute RI adequate to perform a 1RM over 2 sets. Kraemer (8) found a 3-minute RI was adequate to maintain a 10RM over 3 sets. In contradiction to these findings, Willardson and Burkett (28) determined that a 5-minute RI was not adequate to maintain Bpress repetitions using an 8RM over 4 consecutive sets. Similarly, Richmond and Godard (17) found a decline in repetitions over 2 trials separated by 5 minutes using a load of 75% of 1RM. With respect to the four studies (three described above and the present one) using loads between 70 and 90% of 1-RM, it is possible that the training status of the participants in the study which found repetition maintenance (8) was different than that of the participants in the studies which did not.

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Specifically, the participants in the Kraemer (8) study were Division 1 American college football players, whereas the participants in the other 3 studies were recreationally trained. It is likely that the Division 1 football players were better adapted to performing maximal effort Bpress over consecutive sets than were the recreationally trained participants. The results of the present study suggest that when Bpress is performed as the second exercise in a training session, or as half of a paired set, greater than 4-minute RIs are required to maintain VL when using a load of less than 90% of 1RM. It would appear this is also the case for the Bpull exercise when performed as the first exercise in a training session or as half of a paired set.

A relatively large body of literature exists examining the relationship between RI length and volume maintenance. However, the literature has predominantly focused on this relationship over repeated trials of a single exercise. Under the TS condition in the present study, VL was monitored over repeated trials of 2 exercises performed 1 after another. Arguably, this structure more closely mimics a true training session as compared to studies that investigated a single exercise over repeated trials. Not only was a 4-minute RI inadequate with respect to maintaining VL over the initial 3 sets of Bpull, but it was also inadequate in terms of VL maintenance over the subsequent 3 sets of Bpress. Because VL in the first set of Bpress was not significantly different between the 2 conditions, it would seem as if the cumulative effects of performing 3 sets of a 4-RM Bpull with 4-minute RIs, prior to the first set of Bpress under the TS condition, were no different than the effects of performing 1 set of a 4RM Bpull 2 minutes prior to the first set of Bpress under the PS condition. These findings would seem to add to the plausibility that at the onset of the first set of Bpress in the TS protocol the musculature predominantly involved in the Bpress exercise was not in a fatigued state–or, at least, in no more of a fatigued state than if a single set of 4RM Bpull had been performed 2 minutes prior to the onset of the Bpress. The performance of 3 sets of Bpull prior to the onset of 3 sets of Bpress had little effect on the outcome of the Bpress sets. If this is the case, it would seem that in a training session involving agonist/antagonist muscle groups, whereby agonist work is followed by antagonist work, in which volume maintenance is a desired outcome, RI between sets of both the first and second exercises should be similar. With respect to volume maintenance, given the results of the present study, consideration of antagonist work performed prior to agonist work is perhaps unwarranted.

Outcomes in acute efficiency (VL/time) do not necessarily translate into similar outcomes in chronic adaptation. That PS training is an efficient training method as compared to TS training does not necessarily mean PS training is efficient with respect to chronic adaptation. The training-induced outcome is affected by fatigue, the variable largely responsible for determining acute efficiency. It has been suggested that fatigue may, in fact, act as a stimulus for strength development (19). Ultimately, it is the training outcome that is of importance, and therefore fatigue (as reflected in a diminished ability to perform work) may or may not be detrimental or beneficial.

Practical Applications

PS-type training has been prescribed for years by practitioners as a time-effective means of developing strength. However, scientific data to support its efficacy are limited. The current data indicate that heavy resistance (4RM) PS training allows a similar loading to be imposed on the musculature as that achieved with TS training. However, under both the PS and TS conditions VL was not maintained from set to set, suggesting that practitioners aiming to maintain VL may wish to implement RI of greater than 4 minutes when using heavy loads. Further research is required to determine the rest interval necessary for complete recovery when using heavy loads over multiple sets. Predictions as to the chronic effects of PS training would seem premature at this time. However, it is possible that PS training is an efficient, and effective, method of developing strength. If this is the case and practitioners are able to develop strength in a time-efficient manner, more time can be spent on other aspects of athletic development (e.g., skill development). Better use of resources (i.e., time) should theoretically result in the attainment of higher levels of athletic performance. Furthermore, because resistance training has been associated with improved health and a decrease in the risk of chronic disease and disability (24), time-efficient programs would likely have a positive effect on the health of the general population. Practitioners able to offer clients results in less time would likely see an increase in the number of individuals willing to adhere to resistance training programs. More people involved in resistance training would undoubtedly be a benefit in terms of overall population health. Given this possibility, longitudinal studies investigating the chronic effects of PS training are warranted.

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