THE EFFECT OF A COMPLEX AGONIST AND ANTAGONIST RESISTANCE TRAINING PROTOCOL ON VOLUME LOAD, POWER OUTPUT, ELECTROMYOGRAPHIC RESPONSES, AND EFFICIENCY

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ABSTRACT

Robbins, DW, Young, WB, Behm, DG, and Payne, WR. The effect of a complex agonist and antagonist resistance training protocol on volume load and power output, electromyographic responses, and efficiency. J Strength Cond Res 24(7): 1782–1789, 2010–The objective of this study was to investigate the acute effects of performing traditional set (TS) vs. complex set (CS) agonist-antagonist training over 3 consecutive sets, on bench press throw (BPT) throw height (TH), peak velocity (PV), peak power (PP), bench pull volume load (VL), and electromyographic (EMG) activity. Eighteen trained men performed 2 testing protocols: TS comprising 3 sets of Bpull followed by 3 sets of BPT performed in approximately 20 minutes or CS comprising 3 sets of both Bpull and BPT performed in an alternating manner in approximately 10 minutes. Throw height, PV, PP, and EMG activity were not different within, or between, the 2 conditions. Bench pull VL decreased significantly from set 1 to sets 2 and 3, under both conditions. Decreases from set 1 to set 2 were 14.55 ± 26.11 and 9.07 ± 13.89% and from set 1 to set 3 were 16.87 ± 29.90 and 14.17 ± 18.37% under CS and TS, respectively. There was no difference in VL per set, or session, between the conditions. Although there was no augmentation of the power measures, CS was determined to have approximately twice the efficiency (output/time) as compared to TS. Efficiency calculations for VL, TH, PV, and PP are 103.47 kg·min⁻¹, 26.25 cm·min⁻¹, 1.98 m·s⁻¹·min⁻¹, 890.39 W·min⁻¹ under CS and 54.71 kg·min⁻¹, 13.02 cm·min⁻¹, 0.99 m·s⁻¹·min⁻¹, 459.28 W·min⁻¹ under TS. Comparison of EMG activity between the protocols suggests the level of neuromuscular fatigue did not differ under the 2 conditions. Complex set training would appear to be an effective method of exercise with respect to efficiency and the maintenance of TH, PV, PP, and VL.

KEY WORDS complex training, bench press throw, bench pull, efficient

INTRODUCTION

Complex training commonly involves the coupling of a heavy resistance training exercise with a biomechanically similar plyometric exercise performed in an alternating manner (16). A less common complex training design pairs biomechanically dissimilar exercises, targeting agonist and antagonist muscle groups (2). For the purposes of this research, agonist-antagonist complex set (CS) training refers to the coupling of a heavy traditional weight training (e.g., bench pull [BPull]) with a ballistic (e.g., bench press throw [BPT]) exercise, targeting upper-body muscle groups, performed coincidentally. Agonist-antagonist exercises are commonly performed over repeated trials, in an alternating manner, with rest intervals (RIs) between each set.

Resistance training is an effective method for developing muscular strength and power (19) and has been associated with improved health and a decrease in the risk of chronic disease and disability (21). Resistance training schemes able to develop strength and power in a time-efficient manner would be beneficial to athletes and the general population. Agonist/antagonist complex training may be one such training modality. It is possible that by alternating agonist and antagonist exercises, the “density” of work performed could increase. That is, more work could be performed per unit of time. Furthermore, it is possible that gains in “efficiency” are not at the expense of efficacy. Resistance training protocols that save time without compromising efficacy, or increase efficiency, could be advantageous to athletes and the general population.

Peer-reviewed research into the effects of agonist/antagonist complex training is limited. It has been suggested that this type
of training results in acute performance enhancement (2). Baker and Newton (2) observed an augmentation in power output in the BPT when preceded 3 minutes by a set of Bpull, compared to power output achieved in a set of BPT with no intervention. They suggested that antagonist preloading may alter (i.e., shorten the antagonist braking phase) triphasic electromyographic (EMG) activity during subsequent agonist activity. However, the researchers did not incorporate a mechanistic evaluation (i.e., EMG) into the research.

Performance enhancement after antagonist loading has been documented in a single-set study (2). However, CS commonly involves the execution of repeated sets. The second CS also begins with antagonist loading, as do all subsequent sets. Research involving multiple set studies is necessary to draw conclusions as to the likely efficacy of CS as a training method for developing power.

Research investigating complex training and CS has focused primarily on performance enhancement of the second phase (power activity) of the pair. This only represents half of the training protocol. To date, there have been no studies that have examined the first phase of the complex pair. Research studies have commonly viewed the first phase as the “intervention.” However, this phase should not only be viewed solely as a means to augment performance of the subsequent power phase but also as an instrument to develop the targeted musculature. For example, if BPT is preceded by Bpull, Bpull should be seen not only as a means of augmenting performance of BPT but also as a means of developing the musculature involved in the Bpull. Research investigating the first phase of CSs is necessary to draw conclusions as to the efficacy of CS as a method of developing strength.

Although research into complex training has been undertaken primarily with the intent of augmenting performance of the power activity (second phase), it has been suggested that whether performance enhancement is observed, or not, complex training may be a time-efficient method of developing strength and power (6,17). To date, there have been no studies reported that have compared CS to other methods of developing strength and power. Research comparing CS to other training modalities should perform efficiency calculations for both phases of the CS to provide support for the hypothesis that CS is a time-efficient method of developing strength and power.

Performance enhancement after loading has been demonstrated in a single CS. To date, however, there have been no studies reported that have examined the mechanism underlying, or responses to, CS in which an agonist/antagonist pairing of high-resistance isotonic and ballistic exercises are investigated over consecutive sets. It is possible that this method of training could be an efficacious and time-efficient method for developing strength and power. The purpose of this study was to investigate the effect of agonist-antagonist complex training on Bpull and BPT performance and EMG activity over 3 consecutive sets and compare those effects to a traditional training modality in terms of effectiveness and efficiency.

**METHODS**

**Experimental Approach to the Problem**

A within-subject randomized, counterbalanced design was used to investigate the effects of altering agonist and antagonist exercises on BPT and Bpull performance and to determine whether significant differences in BPT throw height (TH), peak velocity (PV), peak power (PP), and Bpull volume load (VL) (load x repetitions) existed between CS and a traditional set (TS) training protocol, over 3 sets. Because of the familiarity of movement and relatively widespread use as a means to develop strength and power, Bpull and BPT were chosen as the pulling and pushing exercises, respectively. Volume load was chosen because of its widespread use as an indicator of work performed over an entire set or session(s). The 3 power performance measures (TH, PV, and PP) are widely used and accepted as variables relating to explosive force production capabilities. The TS protocol was designed to reflect the much-practiced resistance training scheme of targeting one muscle group via multiple sets, before targeting another muscle group. The CS protocol was designed to stress the same musculature as that stressed under the TS condition but in less time.

**Subjects**

Eighteen trained men 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 (predominately basketball and rugby players) with several years training experience and testing occurred during the off-season (the months of May and June). All participants had experience with CS-type training. The participants’ descriptive data are displayed in Table 1. The study was approved by the University Human Research Ethics Committee. Before the investigation, all subjects were briefed on the testing protocols, experimental risks, equipment, and the nature of the study before signing an informed consent document. All participants were asked to refrain from any upper-body training in the 48 hours before each training session.

**Procedures**

Forty percent of bench press 1RM was prescribed for all sets of BPT (4 throws) in both protocols as loads of 30–60% of bench press 1RM and repetitions of 3–5 have been suggested to achieve maximum power output (1,8). A 4RM was prescribed for Bpull 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 (22). A 4RM was chosen because high-intensity loads have been recommended for strength development (5,23). The total time required to complete the testing sessions, and the order in which the exercises were performed, differed between the 2 protocols. Specifically, the PS protocol required approximately half the time to complete, as compared to the TS protocol. To assist in the explanation of any observed differences in TH, PV, PP, and
VL EMG, responses of 4 muscles (pectoralis major, anterior deltoid, latissimus dorsi, and 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 because fatigue-induced changes in these signals can provide an indication of general motor unit activation and signal frequency, respectively (20).

Throw height (cm), PV (m$^{-3}/$C1 s$^2$), and PP (W) were calculated using a position transducer (PT5A linear position transducer, Fitness Technology, Adelaide, Australia). The system comprises a cable-extension potentiometer (distance transducer), USB data collection interface, and custom software (Ballistic Measurement System, Fitness Technology) to accurately measure the vertical movement of the bar. Bench pull VL was measured during all sets of both protocols by multiplying the load by the number of correct repetitions achieved.

Before the commencement of the 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 (ICCs) and percent total error (%TE).

Participants underwent 2 familiarization sessions to determine their 4RM for the Bpull, 1RM for bench press, and to be instructed on exercise technique. To determine 1RM bench press, participants performed a set of 5–10 repetitions using 40–60% of expected maximum, followed 1 minute later by a set of 3–5 repetitions using 60–80% of expected maximum. After a 2-minute RI, 1RM attempts were made with approximately 2-minute RIs between attempts. If an attempt was successful using the correct technique, further attempts were made using increasing increments of weight. To determine 4RM Bpull, participants followed a similar protocol as that described for determining 1RM bench press, but loads of 30–50 and 50–70% were implemented in place of 40–60 and 60–80%, respectively. The last successful attempt was recorded as the participant’s 1RM, or 4RM, in that lift. This procedure was adopted from Stone and O’Bryant (19) with one change rather than 1-minute RIs between attempts, 2-minute RIs were used to better ensure recovery between attempts. The familiarization sessions were performed so that the second session was conducted 1 week before the first testing session, which was performed 1 week before the second testing session. All testing was performed at the same time of the day and a standardized warm-up (specific to the testing protocol) was performed in all sessions.

Before testing, participants performed progressive submaximal exercise. Specifically, participants performed 3 sets of 4 repetitions of Bpull at 60, 80, and 90% of 4RM (calculated from the previously determined 4RM) and 3 sets of 4 throws of BPT using 40% of 1RM (calculated from the previously determined 1RM) at self-determined 50, 75, and 100% of maximal effort. A 4-minute RI was provided between like exercises. Before 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, whereas before the CS testing session, the warm-ups sets were performed in an alternating manner.

When performing BPT (warm-up and testing), participants lay supine on a flat bench, in a Smith Machine that allowed the bar to move only in the vertical plane. The participants’ feet were flat on the floor and head, shoulders, and buttocks

<table>
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<tr>
<th>Variable</th>
<th>Set 1 – set 2</th>
<th>Set 1 – set 3</th>
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*4RM Bpull = 4 repetition maximum bench pull; BPT = bench press throw; VL = volume load; CS = complex set; TS = traditional set.
†Mean (SD) ($n = 18$).
were flat to the bench. The starting position of the bar was touching the chest at the nipples. Participants were instructed to attempt to throw the bar in the vertical plane as high as possible, releasing the bar at elbow extension. The BPull 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 participants' 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. Participants were instructed to keep their head, upper body, and legs flat to the bench. Hand placement and tempo were self-determined for both exercises, and an attempt was made to maintain consistency within participant during and between testing sessions. Participants were permitted to hydrate using water during all testing sessions.

Electromyographic 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.) and acquired with the assistance of proprietary software (EMGworks Acquisition 3.5, Delsys Inc.). Electromyographic signals were amplified by 1,000 with a frequency band-pass of 20–450 Hz (common mode rejection ratio of 92 dB) and recorded at 1,000 Hz (Bagnoli Myomonitor III wireless system, Delsys Inc.). The mean amplitude of the RMS and the MDF, analysis was performed using custom-written software (National Instruments LabVIEW 8, Austin, TX, USA). Data were collected throughout the entire set, for all sets of both Bpull and BPT. Electromyographic 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 and the xiphoid processes. 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 the 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. Before electrode placement, the area of skin was thoroughly prepared with abrasive paper and isopropyl alcohol swabs to improve conductivity of the EMG signal.

<table>
<thead>
<tr>
<th>Variable</th>
<th>CS</th>
<th>TS</th>
<th>ES</th>
<th>CS</th>
<th>TS</th>
<th>ES</th>
<th>CS</th>
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<td>386.56</td>
<td>394.25</td>
<td>0.06</td>
<td>332.76</td>
<td>361.61</td>
<td>0.23</td>
<td>315.37</td>
<td>336.54</td>
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<td>1,034.70</td>
<td>1,094.29</td>
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<td>BPT TH (cm)</td>
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<td>86.11</td>
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<td>85.73</td>
<td>87.63</td>
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<td>87.88</td>
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<td>0.09</td>
<td>262.48</td>
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<td>14.80</td>
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<tr>
<td>BPT PV (m/s)</td>
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<td>304.58</td>
<td>0.01</td>
<td>302.46</td>
<td>304.56</td>
<td>0.11</td>
<td>302.36</td>
<td>303.46</td>
<td>0.09</td>
<td>8,903.92</td>
<td>9,185.61</td>
<td>0.14</td>
<td>6</td>
<td>1.57</td>
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<tr>
<td>BPT PP (W)</td>
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<td>3,046.67</td>
<td>0.11</td>
<td>3,020.66</td>
<td>3,079.71</td>
<td>0.09</td>
<td>3,022.90</td>
<td>3,059.23</td>
<td>0.06</td>
<td>9,185.61</td>
<td>9,185.61</td>
<td>0.14</td>
<td>6</td>
<td>679.08</td>
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Traditional Set Protocol. Before testing, participants performed the standardized warm-up. Testing commenced after a 4-minute RI. Three sets of Bpull were followed by 3 sets of BPT, with a 4-min RI between each set. All sets of Bpull were performed to failure using a previously determined 4RM load. The load and number of correct repetitions completed were recorded for each set. All sets of BPT involved 4 maximal throws. The testing session took approximately 20 minutes to complete.

Complex Set Protocol. Before testing, participants performed the standardized warm-up. Testing procedures similar to those used in the TS protocol were implemented. However, the 3 sets of Bpull were performed in an alternating manner with the 3 sets of BPT. Also, although the RI between like sets

<table>
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<tr>
<th>Variable</th>
<th>CS Value</th>
<th>CS Time (min)</th>
<th>CS Efficiency</th>
<th>TS Value</th>
<th>TS Time (min)</th>
<th>TS Efficiency</th>
</tr>
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<tr>
<td>Bpull VL (kg)</td>
<td>1,034.70</td>
<td>10</td>
<td>103.47 (kg·min⁻¹)</td>
<td>1,094.29</td>
<td>20</td>
<td>54.71 (kg·min⁻¹)</td>
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<tr>
<td>BPT TH (cm)</td>
<td>262.48</td>
<td>10</td>
<td>26.25 (cm·min⁻¹)</td>
<td>260.49</td>
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<td>BPT PV (m·s⁻¹)</td>
<td>19.84</td>
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<td>1.98 (m·s⁻¹·min⁻¹)</td>
<td>19.75</td>
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<td>BPT PP (W)</td>
<td>8,903.92</td>
<td>10</td>
<td>890.39 (W·min⁻¹)</td>
<td>9,185.61</td>
<td>20</td>
<td>459.28 (W·min⁻¹)</td>
</tr>
</tbody>
</table>

*VL = volume load; TH = throw height; PV = peak velocity; PP = peak power; Bpull = bench pull; BPT = bench press throw; CS = complex set; TS = traditional set.
†The final set was initiated at 10 minutes (CS) or 20 minutes (TS), and therefore, the total time to complete the sessions varied slightly (e.g., if 12 seconds was required to complete the final set in the PS protocol; total time to complete the session would be 10.2 minutes).

Figure 1. Single participant rectified triphasic electromyographic (EMG) pattern recorded in volts (V) on the pectoralis major and latissimus dorsi muscles over 700 milliseconds (ms) in the bench press throw exercise.
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 testing session was completed in approximately 10 minutes. Under both conditions, during the RI between sets, participants engaged in passive rest. Verbal encouragement was given throughout testing sessions under both conditions.

Statistical Analyses
The reliability study determined ICCs and %TE for set and session VL over 3 sets for Bpull ranged between 0.91 (6.9%) and 0.97 (12.3%). Paired sample t-tests revealed no significant (p ≤ 0.001) differences between the 2 testing occasions. Intraclass correlation coefficient and (%TE) for TH, PV, and PP over 3 sets for BPT ranged between 0.89 (1.2%) and 0.98 (4.5%). 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.

The set and session totals of TH, PV, and PP for BPT and VL for Bpull were calculated in both testing protocols. These data were analyzed using a 2-way analysis of variance (ANOVA) (2 x 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 CS) and the sets (1–3). Analysis of the data to determine if any significant differences existed between the 2 testing protocols was performed to investigate the influence of CS on the maintenance of TH, PV, PP, and VL. Electromyographic data, (RMS and MDF), were gathered for the first and last repetitions of each set. Electromyographic data were analyzed using a 3-way ANOVA (2 x 3 x 2) with repeated measures to determine whether there were significant main effects or interactions for the type of training (CS and PS), the sets (1–3) and the repetitions (first repetition and last repetition). Efficiency (VL/time, TH/time, PV/time, and PP/time) calculations were also made. The level of statistical significance was set at p ≤ 0.05 for all tests with the exception of the 3-way ANOVA comparing the EMG in CS to TS, and within each condition, which was adjusted using the Bonferroni technique and set at p ≤ 0.001. All statistical tests used SPSS version 16. Effect size calculations were performed on measures of TH, PV, PP, and VL (12) to address the magnitude of the response.

Results
The major finding of this study is that all performance and mechanistic measures were similar under CS, as compared to TS, indicating greater time efficiency under CS. There were no differences in set or session totals for BPT TH, PV, and PP within, or across, the 2 conditions. Bench pull VL decreased significantly from set 1 to set 2 and from set 1 to set 3 in the CS and TS conditions (p < 0.05) with percent changes shown in Table 2. There were no differences in set or session Bpull VL between the 2 conditions. Bench pull VL and BPT TH, PV, and PP data and effect sizes are shown in Table 3. Complex set was determined to be more efficient. Efficiency calculations are shown in Table 4. There was no EMG activity main effect differences or interactions.

Discussion
Complex set training has been prescribed by practitioners as a means of developing strength and power. It has been suggested that this type of training results in acute performance enhancement (2). In the present study, augmentation of the performance measures was not observed. However, BPT TH, PV, PP, and VL were not different per set, or for the session, under the CS and TS conditions. Efficiency calculations determined CS training to have approximately twice the efficiency as compared to TS training. These findings support the hypothesis that CS training allows for enhanced efficiency. Comparisons of EMG data suggest that neuromuscular fatigue is no greater in the CS than in the TS protocol. Although participants in the current study were trained men and predominantly collegiate athletes, it is possible that the findings might apply to other samples or populations (e.g., different age, gender, sporting background, and training history).

It is perhaps not surprising that changes in EMG signal were not observed during sets of BPT. The experimental design in the present study (3 sets of 4 throws with a 4-minute RI between similar biomechanical work) was intended to allow participants to perform BPT in a nonfatigued state. The absence of significant changes in the EMG signal during sets of the Bpull exercise may have been influenced by the fiber-type composition of the monitored muscles and the relative involvement of the muscles in the exercise. Among the 4 monitored muscles in the present study, the latissimus dorsi has the highest percent of type I (fatigue resistant) fibers (14,18) and, as such, is likely the most fatigue resistant. The latissimus dorsi likely plays the major role in the Bpull exercise. It is also possible that the 4RM Bpull was not of sufficient duration to induce significant changes in EMG activity. Behm and St-Pierre (4) observed relatively little decrease in muscle activation (as reflected in the EMG signal) and suggested short-duration contractions (e.g., 4RM) may not result in significant changes in EMG activity as compared with longer duration contractions.

Coactivation refers to the concurrent activation of agonist and antagonist muscles (9,15). A triphasic pattern of EMG activity, whereby a large burst of agonist activity is followed by a shorter “braking” burst from the antagonistic musculature and finally a second agonist burst, has been suggested during rapid or ballistic contractions (10,11,13). The performance of a movement may be partially contingent on the net effect of this activity (3). Baker and Newton (2) suggested that augmentation in BPT performance after loading of the antagonist musculature via a set of 8 ballistic BPulls may have been the result of an alteration in the triphasic pattern. Specifically, the researchers hypothesized that the Bpull altered the timing of the antagonist braking activity during
the subsequent (3-minute postintervention) BPT. They postulated that a shorter braking phase from the antagonist would allow for a longer initial burst from the agonist and thereby allow for an increase in the performance measure. Augmentation in BPT performance was not observed in the present study. This is perhaps because of the implementation of a nonballistic intervention (4RM Bpull) performed for low repetitions (tendency to decrease from sets 1–3) in the present study, as compared with the intervention used by Baker and Newton (2) of 8 ballistic Bpulls. It is also possible, although perhaps unlikely, that performance was enhanced to a similar extent in all 3 sets of CS BPT in the present study. This would not have been observed as a set of BPT without intervention (e.g., before the first set of Bpull) was not performed. However, the 3 sets of BPT performed under the CS condition were not only similar to one another, but also similar to the 3 sets of BPT performed under the TS condition. That is, if some augmentation occurred repeatedly and to the same extent over 3 sets under the CS condition, it must also have occurred under the TS condition. It would seem unlikely that a similar level of augmentation occurred before each set of BPT (under both conditions), as a result of the cumulative effects of the varying exercise performed before that set. Rather, it would seem more likely that there was no augmentation in performance.

It has been suggested that stored elastic energy and the stretch reflex may play a role (i.e., enhance agonist performance) in movements involving antagonist loading immediately before agonist activity (7). However, because of the prolonged RI (i.e., time between antagonist and agonist exercises) and the combination of nonballistic and ballistic movements (Figure 1) used in the present study, and subsequent results, stored elastic energy and the stretch reflex were not considered a factor.

Although BPT performance was not enhanced, all 3 measures of power (TH, PV, and PP) were maintained throughout all sets, and were similar, in both protocols. Fiber-type composition of the musculature primarily involved in pressing, as compared to pulling, exercises suggests that maintenance of performance measures would be less likely in pressing as compared to pulling activities (14,18). This was not observed in the present study. This can perhaps be explained by the nature of the pressing activity (i.e., BPT) in the present study. Unlike the pulling activity in the present study, the pressing activity was not performed to volitional failure. The experimental design in the present study was intended to be nonfatiguing with respect to BPT, thereby allowing participants to maximize power output over each of the 4 throws. Therefore, in the present study, it is perhaps not surprising that BPT TH, PV, and PP were maintained over the 3 sets, whereas Bpull VL, over 3 sets performed to failure, was not. It would seem that 4-minute RIs between like sets of nonfatiguing ballistic exercise (whether interrupted, or preceded, by antagonist work) are sufficient to maintain power. Bench pull VL did not differ between the 2 conditions but did decrease from set 1 to set 2 and from set 1 to set 3 under both conditions. This would seem to indicate that a 4-minute RI, between Bpull sets performed to volitional fatigue, was not adequate for the targeted musculature to recover and maintain VL.

The results of the present study are limited to a single CS performed over 3 trials. Arguably, this is not indicative of a resistance training session targeting multiple muscle groups. It is possible that the maintenance of power measures over a longer training session is not possible. It is also possible that the differences in session VL (see Table 3) in CS as compared with TS, although not statistically different in the present study, could continue to grow over a longer training session and become significant. Furthermore, maintenance of similar acute TH, PV, PP, and VL under CS, as compared with TS, does not necessarily yield equivalent, or efficient, chronic development of strength and power.

**Practical Applications**

Time-constrained coaches and practitioners interested in training strength and power over the same time period (e.g., session, microcycle, or mesocycle) may be well advised to incorporate CS-type training. However, the use of antagonist preloading in an attempt to augment subsequent agonist power output is not recommended. Currently, the data supporting the hypothesis that CS-type training can enhance power output are limited. This study found that over 3 CSs, there were no significant effects on BPT ability as a result of antagonist preloading. Similar maintenance of TH, PV, PP, and VL under CS as compared to TS indicates that similar stress was imposed on the musculature in approximately half the time and suggests efficiency is enhanced under CS. Despite the inability to maintain Bpull VL, BPT performance measures were maintained under the CS condition, suggesting that strength and power training can be combined in this manner without compromising power output. Although similar under both the CS and TS conditions, Bpull VL was not maintained over the sessions, 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 RI necessary for complete recovery when using heavy loads over multiple sets. Predictions as to CS efficacy or efficiency with respect to chronic adaptation would be speculative at this time. However, it is possible that CS training is an efficient, and effective, method of developing strength and power. Practitioners able to develop strength and power in a time-efficient manner will create more time for coaches to develop other components of performance. Conceivably, time-efficient development of strength and power will assist in enhanced athletic performance. Efficient development of strength and power will also have implications for the general population. Resistance training has been associated with improved health and a decrease in the risk of chronic disease and disability (21). Arguably, resistance training programs offering results in less time may be more attractive to greater numbers of the general population.
population. Before prescribing CS-type training to the general population, it is important to ensure familiarity with both high-intensity (e.g., 4RM) and high-velocity (e.g., BPT) exercises. Increased numbers of individuals performing regular resistance training will have a positive effect on the overall health of the general population. Given this possibility, research investigating the chronic effects of CS training is warranted.

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