International Journal of EXERCISE SCIENCE

Original Research

Power Output in Rugby Players Comparing Unilateral and Bilateral Isotonic Upper-Body Resistance Exercise

EVAN NAKACHI†1, JAMES D. GEORGE‡1, ALLEN C. PARCELL‡1, DENNIS L. EGGETT‡2, and J. BRENT FELAND‡1

[1]Department of Exercise Sciences, Brigham Young University, Provo, UT, USA; [2]Department of Statistics, Brigham Young University, Provo, UT, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 12(6): 691-700, 2019. Bilateral deficit (BLD) occurs when the internal muscular force generated during simultaneous bilateral limb exercise is lower than the sum of internal muscular forces generated during separate right limb and left limb unilateral exercise, while attempting to oppose the same total external load. Numerous BLD studies have evaluated force output differences during exercise; however, no study has determined whether BLD exists when generating power during isotonic upper-body exercise. To address this, we measured and compared power output across unilateral and bilateral isotonic upper-body exercise. Seventeen college male rugby players (age = 21.8 ± 2.1 y) completed 4 randomized, equal volume, upper-body exercise sessions: unilateral exercise using traditional weight training (UWT); unilateral exercise using circuit training (UCT); bilateral exercise using traditional weight training (BWT); and bilateral exercise using circuit training (BCT). Five sets of 5 repetitions of each dumbbell exercise (bench press, bent over row, overhead press, biceps curl, front raise, and bent over raise) were completed using a moderate dumbbell load (40–50% of 1-RM). Linear position transducer units were employed to measure power output. Peak and mean power scores (with the power data of all 6 exercises combined within a given group) were significantly higher in UWT compared with the other 3 protocols (p = .0001). This study involving collegiate rugby players demonstrates the presence of a bilateral power deficit in upper-body isotonic exercise and suggests that traditional unilateral exercise may generate the highest power output during a given resistance exercise session involving similar volumes of work.

KEY WORDS: Bilateral deficit, sports conditioning, exercise recovery

INTRODUCTION

Athletic movements like throwing a ball, swinging a racket, putting the shot, and punching are explosive in nature and depend on the ability to generate high levels of muscular power (21). Muscular power is defined as the product of force (strength) and velocity (speed) (23). When training to improve muscular power, resistance exercises should involve powerful movements that optimize an ideal combination of muscular force and speed (5). Jandacka and Uchytil demonstrated that a moderate load (30–50% of 1-RM) allows for an optimal expression of speed that can maximize muscular power output (13). Traditionally, weight training exercise is performed bilaterally with both limbs moving in unison, such as the barbell bench press or barbell squat. Common bilateral barbell exercises for developing power include the push press, push jerk, power clean, and power snatch (3)

Most athletic movements and skills, however, involve unilateral movements where one arm or leg moves independently of the other. For this reason, unilateral weight training may yield better performance development than bilateral weight training, because it is more similar or specific to the actual movements performed on the athletic field (20). Unilateral weight training can be performed with dumbbells of various weights by: 1) performing all repetitions in a given set using one limb exclusively, before repeating the same exercise on the contralateral side; or 2) alternating back and forth between limbs, with each ipsilateral repetition repeated immediately by a contralateral repetition until the given set is completed. Although unilateral exercise provides more movement specificity than bilateral exercise, it may also be advantageous because it does not introduce the problem of bilateral deficit (BLD) (12).

Evidence of the BLD phenomenon has been cited in the literature since the 1960's (22). Bilateral deficit occurs when the internal muscular force generated during simultaneous bilateral limb exercise is lower than the sum of internal muscular forces generated during separate right limb and left limb unilateral exercise, while attempting to oppose the same total external load (11). Numerous BLD studies have documented the existence of a muscular force BLD when comparing upper-body isometric (2, 13, 14) and isokinetic exercise (24), and lower-body isotonic exercise (10). To date, no study has determined whether there is a muscular power BLD when comparing bilateral and unilateral exercise sessions involving isotonic exercise of similar training volumes. The standard calculation for training volume is the product of all work (repetitions x sets x weight) performed during a given exercise session (9). Exercise sessions of the same volume, however, can have different power outputs depending on how fast each lift is performed. Thus, if a muscular power BLD does exist when performing bilateral and unilateral isotonic exercise sessions of a similar volume, then it is conceivable that differences in lifting velocity and muscular power output could exist during and across exercise sessions.

Another variable that may influence the muscular power output during a given exercise session is the type of weight training performed (e.g., traditional weight training versus circuit weight training). Traditional weight training involves performing a given set of repetitions, resting for a prescribed period of time (often 1-3 minutes), and then repeating the exercise and rest sequence until all of the sets for a given exercise are completed. Circuit weight training, on the other hand, involves performing a circuit of different exercises one immediately after the other, with very little rest (usually less than 1 min) between exercises. Typically, the order of exercises across the circuit are organized so that similar muscle groups are not worked consecutively (e.g., an upper-body lift followed by a lower-body lift), giving the muscles more time to rest. Since circuit weight training requires very little total rest time between sets and exercises, the same amount of total work can be completed in about half the time of traditional weight training (6). However, a potential disadvantage of circuit weight training is when the circuit only involves upper-body exercises. In this case, an upper-body circuit training routine may not allow enough time between exercises for a fatigued muscle to recover, so optimal power output may be compromised (7).

This study sought to determine whether peak and mean differences exist in muscular power output between unilateral and bilateral upper-body weight lifting sessions of equal exercise volume. A second purpose was to determine whether peak and mean differences exist in muscular power output between traditional and circuit weight lifting sessions. We hypothesized that unilateral exercise would generate higher peak and mean power scores than bilateral movements, supporting the idea that BLD also exists in isotonic upper-body weight training movements. We also hypothesized that traditional upper-body weight lifting routines would generate higher peak and mean power scores than upper-body circuit weight lifting routines, since traditional weight training allows the worked muscles to more fully recover between repeated exercises.

METHODS

Participants

Seventeen male collegiate national championship-caliber rugby players (age = 21.8 ± 2.1 y; body mass = 93.5 ± 12.5 kg; height = 181.9 ± 5.0 cm) participated in this study. Before data collection, each participant had previously performed at least 1 year of general weight training, and at least 4 months of unilateral dumbbell weight training. All subjects were informed of the benefits and risks of the study prior to signing an informed consent form approved by the University's Institutional Review Board. No injuries were reported throughout the duration of the study.

Protocol

Subjects completed 4 different upper-body weight lifting sessions in random order over a 3-week period, at the same time of day, with at least 48 h of rest between each exercise session. The 4 exercise routines were designated as follows: unilateral exercise using traditional weight training (UWT); unilateral exercise using circuit training (UCT); bilateral exercise using traditional weight training (BWT); and bilateral exercise using circuit training (BCT). Each exercise session began with a 5-min aerobic warm-up on a treadmill at 8 km/h followed by a slow-movement bilateral warm-up set of 5 repetitions of each of the 6 dumbbell exercises at a load of 40–50% of the 1-RM mass. Following the warm-up, each participant completed 5 repetitions and 5 sets of each exercise within each exercise session. The total exercise volume (exercise weight x 5 repetitions x 5 sets) was the same for each participant, for each exercise, and across all 4 training sessions. Dumbbells were placed on the floor approximately 1 meter in front of the participant as a convenience in picking up and setting down the dumbbells between sets.

Each exercise session included the same 6 upper-body dumbbell exercises done in the following order: bench press, bent over row, overhead press, biceps curl, front raise, and bent over raise. The exercises were ordered in this way so identical muscle groups were not exercised on consecutive lifts to minimize fatigue and optimize power (19). Prior to exercise data collection, participants' body mass and height were measured using a balance beam scale [Detecto, Webb City, MO] and stadiometer [MedArt, St. Louis, MO], respectively, with participants wearing lightweight clothing and no shoes. In addition, the one-repetition maximum (1-RM) scores of each upper body exercise were determined using a standard 1-RM protocol (9) and employing bilateral exercise with a dumbbell of the same mass held in each hand. Participants were instructed to perform all dumbbell exercises using a medium weight (40–50% of 1-RM) and to move as fast as possible using correct form. For each bilateral lift, dumbbells of the same mass were held in each hand and moved simultaneously. For each unilateral lift, dumbbells of the same mass were also held in each hand but only one arm was exercised at a time. All exercises were performed using standard weight lifting technique (3) and observed by the same primary researcher who was certified as a strength and conditioning coach.

Unilateral exercises were performed with either the right arm or left arm working independently. For a given unilateral exercise, the right arm was always exercised first and then the left arm. For each respective bilateral exercise, both arms worked in unison using the identical same-mass dumbbells employed in each respective unilateral exercise. The traditional weight training protocols involved completing all 5 sets of a given upper-body exercise before moving on to the next exercise, with a 1-min rest period between each set and each exercise. The circuit training protocols involved completing 1 set of all 6 upper-body exercises consecutively as a circuit, with only minimal rest between each exercise (~10 s). Following the first circuit, the next 5 circuits were completed in like fashion, with minimal rest (~25 s) between each circuit.

A linear position transducer (LPT) optical encoder [GymAware, Canberra, Australia] was employed to measure power output of each repetition across all exercises. Previous research shows that this LPT unit provides valid measures of both peak and mean power in the bench press as compared to these measurements calculated by time and displacement as determined by digital video (8). Peak force and peak power data from this LPT unit has also demonstrated accurate correlations with corresponding force plate measurements (4). This LPT unit is also capable of measuring both vertical and horizontal displacement across a given movement pattern in order to calculate angle measurements (4, 8); consequently, this LPT unit can accurately measure power output during upper-body weight training exercises.

In this study, two LPT units were utilized to measure the movement displacement and duration of each dumbbell exercise; one LPT unit designated for the right arm and a second LPT unit designated for the left arm. Each LPT unit included a spring-powered retractable cord and an optical encoder. The retractable cord was fitted with a #2 S-biner double-gated carabiner that could be securely hooked onto a metal ring that was securely attached to the backside of the weight lifting glove worn by participants. The LPT unit's built-in magnets were centered horizontally onto 4.5 kg metal plates placed on the floor and participants were positioned so each exercise movement was performed perpendicular to the LPT units. All of the time-displacement data were sent wirelessly to two iPad devices, where the data were processed to compute power output based on the movement velocity and the mass of the dumbbell (4).

Statistical Analysis

A within-subjects repeated measures statistical design was employed to determine the difference in power output between unilateral and bilateral upper-body exercise, involving both traditional weight training and circuit training routines. The dependent variables for power output were peak power and mean power expressed in watts (W). The independent variables were the 4 randomly assigned exercise sessions that comprised all possible combinations for comparing bilateral and unilateral exercise across both traditional and circuit training routines. This allowed 2 direct-level comparisons and 1 mixed-level comparison for each exercise session. To eliminate any possible confounding factors, the order of the exercise sessions was randomized using the Latin-square design.

The data were analyzed for statistical significance using the JMP Pro 11 [SAS Institute Inc., Cary, NC]. The peak power and mean power scores for a given exercise routine were respectively combined into summed scores (involving all 6 upper-body exercises) across each of the 4 exercise routines. The 4 exercise routines were then compared using a mixed model ANCOVA with a 4 × 5 × 2 (group × set × side [R, L]) blocking on subjects with the vertical distance moved during the exercise as a covariant and a Tukey's posthoc test as needed ($p < .05$).

RESULTS

The results of this study demonstrate that unilateral exercise using traditional weight training (UWT) generates the highest peak (see Table 1 and Figure 1; $p = .0001$) and mean (see Table 2 and Figure 2; $p = .0001$) power output as compared with bilateral traditional weight training (BWT), unilateral circuit training (UCT), and bilateral circuit training (BCT). No significant differences in peak or mean power existed between the other 3 groups. The mean time to complete each exercise session was longer for the traditional weight training groups (UWT = 32.4 min and BWT = 29.5 min) and shorter for the circuit training groups (UCT = 11.9 min and BCT = 10.0 min).

Table 1. Peak power scores (W) for each exercise and protocol[a] ($n = 17$).

	Protocol	Mean	SE	Level[b]		Protocol	Mean	SE	Level
Bench Press	UWT	477.4	20.1	A	Bent Over Row	UWT	704.3	28.8	A
	UCT	417.6	20.1	B		UCT	572.3	28.8	B
	BWT	410.5	20.2	B, C		BWT	510.8	28.5	B, C
	BCT	381.4	20.1	C		BCT	469.8	29.3	C
Overhead Press	UWT	474.1	19.9	A	Biceps Curl	UWT	372.3	18.3	A
	UCT	379.4	19.9	B		UCT	329.7	18.1	B
	BWT	354.8	20.0	B, C		BWT	318.6	18.2	B
	BCT	322.2	20.0	C		BCT	305.4	18.3	B
Front Raise	UWT	590.5	24.9	A	Bent Over Raise	UWT	799.8	35.5	A
	UCT	461.1	24.9	B		UCT	600.5	36.3	B
	BWT	454.5	25.0	B		BWT	523.5	35.6	C
	BCT	412.7	24.8	B		BCT	410.5	36.2	D

[a]Protocols: UWT = unilateral traditional weight training; UCT = unilateral circuit training; BWT = bilateral traditional weight training; BCT = bilateral circuit training. [b]Levels connected by same the letter are not significantly different ($p > .05$).

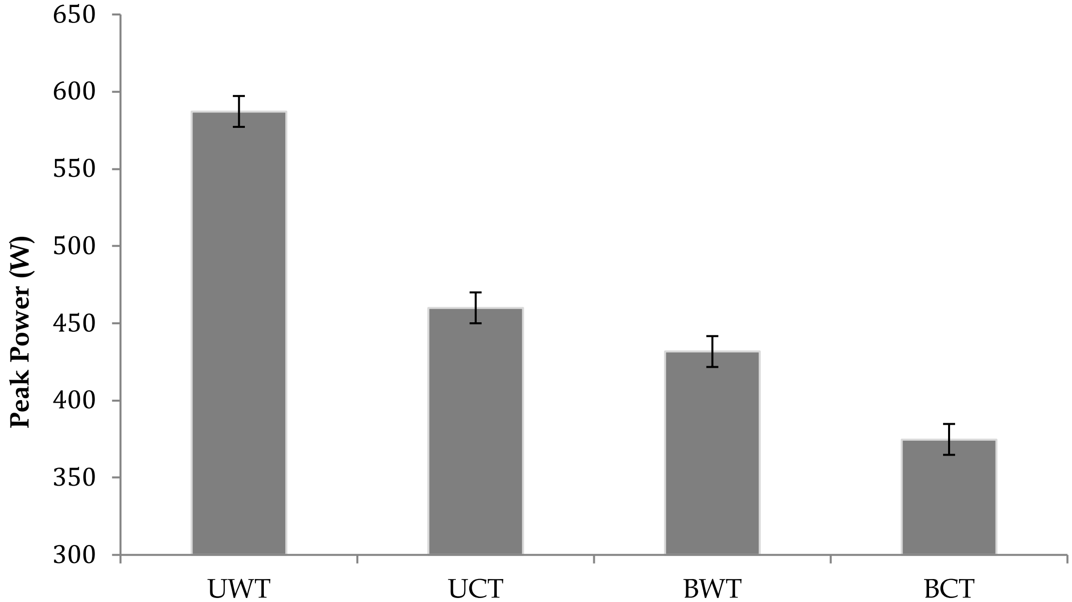

Figure 1. Peak power scores (W) of all 6 exercises combined for a given protocol (*n* = 17)

Table 2. Mean power scores (W) for each exercise and protocol[a] (*n* = 17).

	Protocol	Mean	SE	Level[b]		Protocol	Mean	SE	Level
Bench Press	UWT	277.2	11.4	A	Bent Over Row	UWT	357.9	12.5	A
	UCT	243.5	11.4	B		UCT	291.1	12.6	B
	BWT	240.5	11.4	B,C		BWT	270.7	12.5	B, C
	BCT	224.2	11.4	C		BCT	244.4	12.7	C
Overhead Press	UWT	288.8	11.7	A	Biceps Curl	UWT	166.0	9.6	A
	UCT	222.0	11.7	B		UCT	149.2	9.6	B
	BWT	220.1	11.7	B		BWT	147.6	9.6	B
	BCT	190.2	11.6	C		BCT	136.0	9.6	B
Front Raise	UWT	230.4	10.2	A	Bent Over Raise	UWT	367.1	17.0	A
	UCT	189.6	10.2	B		UCT	264.3	17.4	B
	BWT	180.3	10.2	B, C		BWT	244.7	17.1	B
	BCT	159.3	10.2	C		BCT	195.2	17.3	C

[a]Protocols: UWT = unilateral traditional weight training; UCT = unilateral circuit training; BWT = bilateral traditional weight training; BCT = bilateral circuit training (BCT). [b]Levels connected by same the letter are not significantly different ($p > .05$).

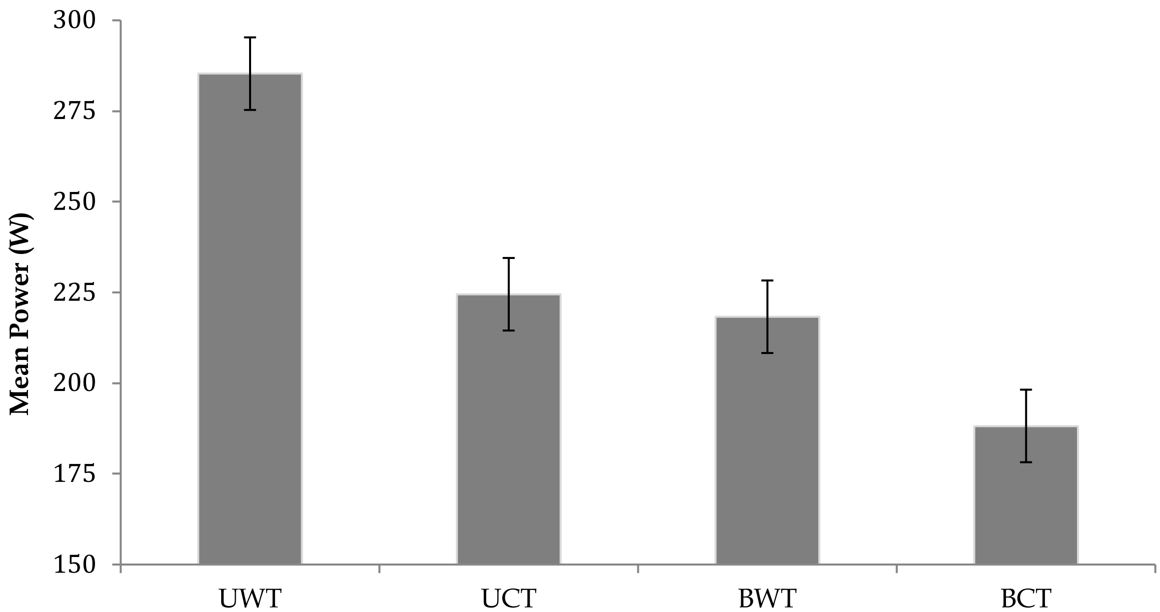

Figure 2. Mean power scores (W) of all 6 exercises for a combined protocol (n = 17).

DISCUSSION

Previous bilateral deficit (BLD) research corroborates our findings and suggests that unilateral exercise generates a higher power output than bilateral exercise because of an inhibitory influence in the neural drive from the brain to the activated muscles (16). If BLD exists, upper-body unilateral exercise may be more effective than bilateral exercise when power training. The collegiate Rugby athletes in the present study generated higher peak and mean power outputs using unilateral upper-body exercise compared to bilateral exercise. This may lead to greater gains in power during a power-development program. McCurdy et al., for example, found that unilateral squats performed twice a week elicited significantly ($p < .0001$) greater improvements in vertical jump scores than did bilateral squats performed twice a week (15). Although the McCurdy et al. study (15) involved the lower-body, a similar outcome seems plausible using a unilateral upper-body power training program. Therefore, the results of our study could also have practical application to athletes. It is currently unknown whether unilateral exercise routines are more effective than bilateral exercise routines when comparing power outputs of known quantities across training programs.

The results of the present study demonstrate that traditional weight training, with more total rest time between exercises and sets, generates a greater power output than circuit weight training (Tables 1 and 2). This supports the hypothesis that shorter rest periods can adversely affect power output (1, 25). Ratamess et al., for example, reported the greatest reduction in bench press power output following a 1-min rest as compared to a 3-min rest (17), while Abdessemed et al. found a significant reduction in bench press power output in 1-min rest periods compared to 3-min and 5-min rest periods (1). In this study, the shorter rest periods (~1-min) employed in the traditional weight training sessions may have provided insufficient rest compared with longer rest periods (3-5 min), but the results clearly show that circuit training, with even less rest (~10-s), resulted in a significant decrease in power output (Tables 1 and 2).

Participants in this study performed each unilateral or bilateral exercise repetition as fast as possible using moderate load dumbbells (about 40-50% 1-RM) to optimize muscular power output, which requires an ideal combination of muscular force and movement speed (5). Had our participants lifted very light dumbbells (< 30% 1-RM), they could have moved faster, but the muscular force and resultant muscular power would have been less. Likewise, had our participants lifted heavier dumbbells (> 60% 1-RM), they could have generated higher levels of muscular force, but movement velocity and resultant muscular power would have been lower. Generating optimal power is a balancing act between muscular force and movement velocity that appears to be optimized at a moderate load (30–50% of 1-RM), as demonstrated by Jandacka and Uchytil (13).

Considering that our participants lifted the same-mass dumbbells in each hand for the unilateral and bilateral exercises, the BLD influence caused the dumbbell mass to feel slightly heavier when performing bilateral movements and slightly lighter for the unilateral movements, even though the dumbbells were identical in mass. Consequently, the participants moved the weight faster when performing the unilateral lifts which generated higher peak and mean muscular power scores when compared to the bilateral lifts (Tables 1 and 2). It is conceivable that within the range of 30-50% 1-RM unilateral lifts would consistently generate a higher level of muscular power than bilateral lifts, assuming the dumbbell mass is constant for both.

Despite the possible power-enhancing advantage of performing unilateral exercise during traditional exercise routines with optimal rest, the total time to complete a given workout may be a concern in terms of time-efficiency. In the present study, the upper-body traditional exercise protocols required about 30 min to complete, while the upper-body circuit training protocols required about 10 min. This 20-min difference is due to the difference in rest and recovery time between the traditional and circuit training protocols. To reduce training time yet maintain an optimal work-to-rest ratio, the athlete could perform fewer sets of each upper-body exercise or fewer total exercises. However, the time required to perform an upper-body workout, similar to the UWT protocol, appears to be realistic for most athletes.

This study's findings are meaningful, but additional research is warranted. Future studies are needed to ascertain whether exercise sessions generating the same muscular power output, regardless of the mode of movement (unilateral versus bilateral), equipment (dumbbells versus barbells), and type of training (traditional versus circuit), provide the same improvement in muscular power over time. It would be interesting to ascertain whether a particular mode of movement, equipment, or type of training can influence improvements in core muscle activation and postural stabilization, movement pattern quality, exercise compliance, and the overall enjoyment of the exercise.

Currently, bilateral exercise is used more in power-development training programs; yet unilateral exercise more effectively mimics sport-specific movements and may generate higher power output scores. Expressing high levels of muscular power is essential for success in athletics and sports. Unilateral exercise with sufficient rest and recovery between exercises (3-5 minutes) might further enhance power-development training programs. In conclusion, this study demonstrates the presence of a bilateral power deficit in upper-body isotonic exercise and suggests that unilateral exercise can generate the highest power output during a given resistance exercise session involving similar volumes of work. Based on this finding, unilateral exercise could be an important programming consideration for strength and conditioning coaches when seeking to optimize muscular power in their athletes.

REFERENCES

1. Abdessemed D, Duche P, Hautier C, Poumarat G, Bedu M. Effect of recovery duration on muscular power and blood lactate during the bench press exercise. Int J Sports Med 20(6): 368-373, 1999.

2. Aune TK, Aune MA, Ettema G, Vereijken B. Comparison of bilateral force deficit in proximal and distal joints in upper extremities. Hum Mov Sci 32(3): 436-444, 2013.

3. Caulfield S, Berninger D. Exercise technique for free weight training and machine training. Essentials of strength training and conditioning. Champaign: Human Kinetics; 2016.

4. Crewther BT, Kilduff LP, Cunningham DJ, Cook C, Owen N, Yang GZ. Validating two systems for estimating force and power. Int J Sports Med 32(4): 254-258, 2011.

5. Cronin J, Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. Sports Med 35(3): 213-234, 2005.

6. Deminice R, Sicchieri T, Mialich MS, Milani F, Ovidio PP, Jordao AA. Oxidative stress biomarker responses to an acute session of hypertrophy-resistance traditional interval training and circuit training. J Strength Cond Res 25(3): 798-804, 2011.

7. de Salles BF, Simao R, Miranda F, Novaes Jda S, Lemos A, Willardson JM. Rest interval between sets in strength training. Sports Med 39(9): 765-777, 2009.

8. Drinkwater EJ, Galna B, McKenna MJ, Hunt PH, Pyne DB. Validation of an optical encoder during free weight resistance movements and analysis of bench press sticking point power during fatigue. J Strength Cond Res 21(2): 510-517, 2007.

9. Earle RW. Weight training exercise prescription. Essentials of personal training symposium workbook. Lincoln: NSCA Certification Commission; 2006.

10. Hay D, de Souza VA, Fukashiro S. Human bilateral deficit during a dynamic multi-joint leg press movement. Hum Mov Sci 25(2): 181-191, 2006.

11. Henry F, Smith L. Simultaneous vs. separate bilateral muscular contractions in relation to neural overflow theory and neuromotor specificity. Res Q Am Assoc Health Phys Educ 32(1): 42-46, 2013.

12. Jakobi JM, Chilibeck PD. Bilateral and unilateral contractions: Possible differences in maximal voluntary force. Can J Appl Physiol 26(1): 12-33, 2001.

13. Jandacka D, Uchytil J. Optimal load maximizes the mean mechanical power output during upper extremity exercise in highly trained soccer players. J Strength Cond Res 25(10): 2764-2772, 2011.

14. Koh TJ, Grabiner MD, Clough CA. Bilateral deficit is larger for step than for ramp isometric contractions. J Appl Physiol 74(3): 1200-1205, 1993.

15. McCurdy KW, Langford GA, Doscher MW, Wiley LP, Mallard KG. The effects of short-term unilateral and bilateral lower-body resistance training on measures of strength and power. J Strength Cond Res 19(1): 9-15, 2005.

16. Oda S, Moritani T. Movement-related cortical potentials during handgrip contractions with special reference to force and electromyogram bilateral deficit. Eur J Appl Physiol 72(1): 1-5, 1995.

17. Ratamess NA, Chiarello CM, Sacco AJ, Hoffman JR, Faigenbaum AD, Ross RE, 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.

18. Rejc E, Lazzer S, Antonutto G, Isola M, di Prampero PE. Bilateral deficit and EMG activity during explosive lower limb contractions against different overloads. Eur J Appl Physiol 108(1): 157-165, 2010.

19. Robbins DW, Young WB, Behm DG, Payne WR, 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.

20. Sale DG. Neural adaptation to resistance training. Med Sci Sports Exerc 20(5 Suppl): S135-145, 1988.

21. Sheppard JM, Cronin JB, Gabbett TJ, McGuigan MR, Etxebarria N, Newton RU. Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. J Strength Cond Res 22(3): 758-765, 2008.

22. Škarabot J, Cronin N, Strojnik V, Avela J. Bilateral deficit in maximal force production. Eur J Appl Physiol 116(11): 2057-2084, 2016.

23. Stone MH, O'Bryant HS, McCoy L, Coglianese R, Lehmkuhl M, Schilling B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. J Strength Cond Res 17(1): 140-147, 2003.

24. Taniguchi Y. Lateral specificity in resistance training: The effect of bilateral and unilateral training. Eur J Appl Physiol 75(2): 144-150, 1997.

25. Willardson JM. A brief review: Factors affecting the length of the rest interval between resistance exercise sets. J Strength Cond Res 20(4): 978-984, 2006.