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Unilateral Traditional Weight Lifting Generates Greatest Acute Upper Body Power Output

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ABSTRACT

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Bilateral deficit (BLD) is a phenomenon where the force generated from simultaneous bilateral limb contractions is less than the sum force generated by separate right and left limb contractions. There have been many BLD studies, but the measures of force generation have predominantly been with isometric and isokinetic contractions. There are, however, no dynamic upper body isotonic unilateral weight lifting studies on acute power output. The purpose of this study was to determine acute power output between bilateral and unilateral weight lifting under the conditions of traditional and circuit weight lifting. Seventeen male BYU rugby players (age = 21.8 ± 2.1 years; mass = 93.5 ± 12.5 kg; height = 181.9 ± 5.0 cm) participated in the study. Each subject participated in 4 randomized weight lifting testing sessions separated by at least 48 h. Each weight lifting protocol included 6 dumbbell lifts (bench press, bent over row, overhead press, bicep curls, front raise, and bent over raise) performed as explosively as possible for 5 sets of 5 repetitions at 40–50% of 1RM. GymAware [GYM] units measured power output for the right and left arms. Peak and mean power (of all lifts combined) was greatest in the unilateral traditional weight lifting (UTWL) group compared to all other groups ($p < .0001$ for each comparison). No significant differences in overall peak and mean power (all lifts combined) existed between the other 3 groups. UTWL peak and mean power outputs were significantly highest for all lifts. UTWL and bilateral traditional weight lifting (BTWL) generated the second or third highest peak power outputs for all lifts, but they were not statistically different from each other except for the bent over raise. Bilateral circuit weight lifting (BCWL) generated the lowest peak power output in all lifts, but was not statistically different from the third lowest peak power output except for the bent over raise. Our study determined that dynamic upper body isotonic unilateral movements generate significantly greater power output than dynamic upper body isotonic bilateral movements using free weights. It was also concluded that traditional weight lifting protocols generated greater power output than circuit weight lifting protocols.

Keywords: power output, bilateral deficit, circuit weight lifting, bilateral weight lifting

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Introduction

Athletic movements like throwing a ball, swinging a racket, putting the shot, and punching are explosive in nature. With these types of movements muscular power is a major determinant of athletic performance (38). Muscular power is defined as work produced in a given time and is the product of force (strength), and velocity (speed) (40). When training for muscular power, weight lifting programs that generate maximal power output are most effective (8) and should be implemented to improve athletic performance. To fulfill this need, many weight lifting programs use bilateral traditional weight lifting (BTWL), such as the barbell bench press.

Many athletic movements and skills are not bilateral but unilateral in nature. For these athletic movements and skills, unilateral traditional weight lifting (UTWL) may produce greater performance development than BTWL because it is more specific to these movements (37). UTWL is performed one limb at a time and can be done in a consecutive manner by completing all targeted repetitions on one limb before going to the contralateral limb to complete the set. It can also be done in an alternating manner by completing a repetition on one limb followed immediately by a repetition of the contralateral limb in a repeated fashion until the targeted repetitions are completed. UTWL may be more specific to many athletic movements than BTWL, but it also could have the advantage of generating superior power output than BTWL because of bilateral deficit (BLD) (18).

BLD is a phenomenon where the force generated from simultaneous bilateral limb contractions is less than the sum force generated by separate right and left limb contractions (37). There have been many BLD studies, but the measures of force have predominantly been with isometric (3, 17, 20, 21) and isokinetic (13, 22, 41, 42) contractions. This is because of the technical difficulty of measuring power output during a free-weight isotonic contraction maneuver compared to either an isometric or isokinetic contraction (14). However, most athletic movements are not isokinetic or isometric in nature, so these types of power measurements may not apply directly to most athletic movements (14). BLD studies that measured lower body isotonic movements all found the presence of BLD (5, 16, 34). Most of the upper body BLD studies measuring isometric and isokinetic contractions have also found the presence of BLD (28, 41, 42). In other words, BLD studies measuring lower body isotonic movements and BLD upper body isometric and isokinetic studies have found that power output is greater with unilateral movements compared to bilateral movements. This suggests that isotonic upper body movements may also find the presence of BLD. There are, however, no upper body isotonic BLD studies on acute power output, so it is not known if BLD is present and if upper body unilateral isotonic movements generate greater acute power output than bilateral isotonic movements.

During BTWL when exercise volume is low and where sets are nonexhaustive, shorter rest periods of 1 min or less can be used without compromising power output (29). However, when exercise volume is high and the sets are exhaustive, rest periods of 1 min or less will compromise power output and rest periods of 2–5 min are necessary to generate optimal power output (44). In a BTWL bench press study that included 10 sets of 6 repetitions at 70% of 1RM, rest periods of 1 min significantly reduced power output compared to 3-min and 5-min rest periods during the last 7 sets for repetitions 4, 5 and 6 (1). When workout time is limited and long rest periods of BTWL are used, the lifters may not be able to complete their full workout and training adaptations can be compromised (31). To overcome the challenge of not completing a full workout because of time constraints, bilateral circuit weight lifting (BCWL) can be implemented. BCWL replaces passive rest periods of BTWL with active rest by including other exercises with short rest periods between exercises so the same amount of work can be completed in half the time as BTWL (12). A study that compared a BCWL protocol that included the bench press, leg extension and ankle extension exercises with 35 s of rest between exercises generated the same bench press power output as a BTWL protocol that consisted of bench press only with 3 min of passive rest between sets (2). The previous study included lower body exercises with the bench press so the rest periods between the bench press in the circuit protocol were similar to the bench press-only protocol and may provide an explanation for similar bench press power output. In contrast, a BCWL protocol that includes only upper body exercises with rest periods of less than 1 min may not allow the upper body muscles time to fully recover, so optimal power output may be compromised (11). However, BCWL studies with only upper body exercises and rest periods less than 1 min have not measured acute power output so it's not known if short rest periods adversely affect upper body muscular power output.

There has been a recent increase in popularity in high intensity circuit training such as CrossFit training (39). A CrossFit training session often includes selection of multi-joint exercises such as the squat, power clean, overhead press and pull-up performed with high loads as quickly as possible with no determined rest periods. Some goals of a CrossFit program are to lift the same amount of weight in shorter periods of time or to complete more work in the same given time (39). Since the lifter is attempting to complete the lifts as quickly as possible, rest periods are very short and often less than 1 min and power output could be adversely affected. Although CrossFit training has been shown to develop aerobic capacity and improve body composition (39), it is not known if power output is compromised with this type of training. There is a need to determine if isotonic upper body BCWL with rest periods of less than 1 min adversely affects muscular power and generates significantly less power output than BTWL. Considering the deficit in the literature regarding unilateral work, there is also the need to determine if BLD exists in isotonic upper body movements and if UTWL generates significantly greater power output than BTWL. Furthermore, it is important to know if BLD exists in unilateral circuit weight lifting (UCWL).

The purposes of this study were to examine if there are differences in power output between bilateral and unilateral weight lifting under the conditions of traditional and circuit weight lifting and to determine which weight lifting protocol generates the greatest general upper body power output. We hypothesized that UTWL would generate the greatest general upper body power output. We also hypothesized that traditional weight lifting would generate greater power output than circuit weight lifting, with shorter rest periods negatively affecting power. Finally, we hypothesized that unilateral movements would generate superior power output than bilateral movements, supporting the notion that BLD exists in isotonic weight lifting. According to these hypotheses, UTWL would generate the highest power output, and BCWL the lowest power output.

Methods

Experimental Design

This study employed a within-subjects repeated measures research design to determine the differences in power output between bilateral and unilateral weight lifting under the conditions of traditional and circuit weight lifting. The independent variables were 4 weight lifting protocols that constituted all possible combinations for comparing bilateral and unilateral weight lifting under the condition of traditional and circuit weight lifting. This presented 2 direct-level comparisons and 1 mixed-level comparison for each weight lifting protocol. To eliminate any possible confounding factors, the order of the weight lifting protocols was randomized using the Latin-square design. The 4 weight lifting protocols were: (protocol 1) unilateral traditional weight lifting (UTWL), (protocol 2) unilateral circuit weight lifting (UCWL), (protocol 3) bilateral traditional weight lifting (BTWL), and (protocol 4) bilateral circuit weight lifting (BCWL). Subjects were randomly assigned to all weight lifting protocols. The initial session included signing of informed consent forms, subject's anthropomorphic documentation, determination of load for all lifts, detailed explanation and demonstrations of all lifts and weight lifting protocols. Dependent variables for power output were peak power (W) and mean power (W). These measures of power have been tested and found to be valid for upper body exercises like the bench press (14) with high test-retest reliability (26).

Subjects

Seventeen male BYU rugby players (age = 21.8 ± 2.1 years; mass = 93.5 ± 12.5 kg; height = 181.9 ± 5.0 cm) who had at least 1 year of weight lifting experience and at least 4 months of unilateral dumbbell weight lifting experience as verified by the strength coach participated in the study. Testing of 1-repetition maximum (1RM) and anthropometric measurements for the study were conducted as part of each subject's strength and conditioning program. All subjects read and signed an informed consent form approved by the Institutional Review Board at Brigham Young University. No injuries were acquired through participation in this study.

Procedures

Each subject came in for 4 testing sessions separated by at least 48 h. The subjects were in-season, so testing sessions were not scheduled the day before or the day after games. With these restrictions all subjects completed their 4 testing sessions in 2–3 wk. In each testing session the subjects did 1 of 4 randomized weight lifting protocols. Each weight lifting protocol included 6 dumbbell lifts with 5 sets of 5 repetitions performed for each lift. The 6 lifts include the bench press, bent over row, overhead press, bicep curls, front raise, and bent over raise.

The dumbbell bench press started with the subject in a supine position on the bench with head, shoulders, and hips on the bench and feet flat on the floor on opposite sides of the bench. The subject started the lift in the bottom position with the dumbbell handles parallel to the floor, in line with the top of the chest, with the dumbbells touching the lateral sides of the pectoralis major, and the upper arms positioned 45 degrees from the sagittal plane of the body. Upon readiness and on the investigator's signal the subject lifted the dumbbells vertically in the sagittal plane until the elbows were completely extended and thereafter returned to the starting bottom position. The cycle was repeated until the targeted repetitions were completed. No part of the body was allowed to leave the bench during the lift.

The dumbbell bent over row began with the subject in a stance less than shoulder width apart in a ¾ squat position, with hips and knees flexed, the upper torso extended and positioned 30 degrees to the floor. The lift began in the bottom position with the subject holding the dumbbells with the palms facing medially in the sagittal plane and elbows extended. Upon readiness and on the investigator's signal the subject lifted the dumbbells vertically in the sagittal plane until the elbows reached the fully flexed position and thereafter returned to the starting bottom position. The upper torso remained in the starting position throughout the entire lift with no plantar flexion during attempts.

The dumbbell overhead press initiated with the subject standing in the neutral position, the feet shoulder width apart, the elbows and shoulders flexed, the dumbbells held in the bottom position at shoulder height and the palms facing medially in the sagittal plane. Upon readiness and on the investigator's signal the subject lifted the dumbbells vertically in the sagittal plane by completely extending the elbows and flexing the shoulders and thereafter returned to the starting bottom position. The upper torso remained in the neutral position with the hip and knee extended throughout the entire lift with no plantar flexion during attempts.

The dumbbell bicep arm curl proceeded with the subject standing in the neutral position, the feet shoulder width apart, holding the dumbbells in the bottom position, with the palms in the supinated position 30 degrees to the frontal plane. Upon readiness and on the investigator's signal the subject lifted the dumbbells in the sagittal plane by flexing the elbows until the elbows were fully flexed and thereafter returned to the starting bottom position. The upper torso remained in the neutral position with the hip and knee extended throughout the entire lift with no plantar flexion during attempts.

The dumbbell front raise started with the subject standing in the neutral position, the dumbbells held in the bottom position, elbows extended, palms facing medially in the sagittal plane. Upon readiness and on the investigator's signal the subject flexed the shoulders and lifted the dumbbells in the sagittal plane until the arms were parallel to the ground and thereafter returned to the starting bottom position. The upper torso remained upright with no trunk hyperextension, and the hips and knees in the extended position throughout the entire lift.

The dumbbell bent over raise began with the subject in a shoulder width stance in a ¾ squat position, with hips and knees flexed, the upper torso extended and positioned 30 degrees to the floor. The subject held the dumbbells in the bottom position with the palms facing medially in the sagittal plane and elbows extended. Upon readiness and on the investigator's signal the subject horizontally abducted the shoulders and lifted the dumbbells in the upper body's transverse plane until the arms were parallel to the ground and thereafter returned to the starting bottom position. The upper torso remained positioned 30 degrees to the floor with the hips and knees in the same flexed position throughout the entire lift with no plantar flexion during attempts.

Instruments

The GymAware [GYM] linear position transducer (LPT) optical encoder (Kinetic Performance Technology, Canberra, Australia) measured power output of every repetition for all 6 lifts. The GymAware optical encoder is a valid method of evaluating both peak and mean power in the bench press and squat movements as compared to these measurements calculated by time and displacement determined by digital video (14). Peak force and peak power data from the GymAware LPT correlated significantly with corresponding force plate measurements ($P < 0.05–0.001$) (7). The GymAware LPT optical encoder is the only LPT that calculates angle measurements. Therefore the GymAware optical encoder is capable of measuring true vertical displacement when some horizontal displacement is present in the measured movement (7, 14). Therefore, it was concluded that the GymAware optical encoder LPT is a valid tool to measure power output during various weight lifting exercises.

Two separate GymAware units measured displacement and time of every lift for the right and left arms by attaching the LPT's spring-powered retractable cord with a #2 S-BINER double-gated carabiner to a ring sewed onto the center of the backside of a weight lifting glove worn by the subjects. The GymAware units were pre-tested and marked right or left so the same unit was used for the right arm and left arm respectively during all testing sessions. The spring-powered retractable cord is attached to an optical encoder and is enclosed in the GymAware unit. The GymAware unit's built-in magnets were centered horizontally to 4.54 kg metal weight lifting plates placed on the floor in line and .77 m apart. The time-displacement data was sent wirelessly to 2 iPad devices and the data was used to calculate movement velocity and factored in with the mass of the load lifted to determine power output of the movements (7). All lifts were done in the same manner as previously described in addition to positioning the subjects so the lifts were performed perpendicular to the GymAware units. To assure that the iPad devices were ready to collect data, the subject started each set at the signal of the primary investigator.

Weight Lifting Protocols

All testing sessions began with a 5-min aerobic warm-up on a treadmill at 8 km/h followed by a warm-up set of 5 repetitions for each exercise with 40–50% of 1RM. Each weight lifting protocol included the same exercises done in the following order: Bench press, bent over row, overhead press, bicep curl, front raise, and bent over raise. The lifts were organized so that the same muscle groups were not exercised on consecutive lifts to optimize power output (35). The bench press was paired with the bent over row; the overhead press was paired with the bicep curl, and the front raise was paired with the bent over row. All lifts were done as explosively as possible for 5 sets of 5 repetitions at 40–50% of 1RM. Loads of 30–50% of 1RM have been shown to generate maximal power output during the bench press (19). To reduce confusion and dumbbell transition time, the same dumbbells were used for paired lifts (e.g., 18.2 kg dumbbells were used for both bench press and bent over row). The first lifts of the paired lifts were set at 40% of 1RM. All lifts were performed within 40–50% of 1RM following this procedure. All dumbbells used during the testing session were placed on the floor ~1 m in front of the lifting area to minimize dumbbell transition time. Lifts were done as previously described and according to the following 4 weight lifting protocols.

With UTWL all exercises were performed in a unilateral manner working one arm at a time. The lifts were performed in a consecutive manner completing the targeted repetitions on one arm and ending in the bottom position before going on to complete the targeted repetitions on the contralateral arm. To avoid confusion during the unilateral weight lifting protocols each set began with the right arm. With the traditional weight lifting protocols, all required sets for each exercise were completed before moving on to the next exercise. There were 1-min rest periods between sets and exercises because the sets were submaximal in nature. This rest period was selected despite previously stating that rest periods of 2–5 min between sets are necessary to optimally generate muscular power after repeated exhaustive sets (44). In our study the traditional weight lifting protocol sets were low in work volume and not repeated exhaustive sets. As previously mentioned, when exercise volume is low and where sets are nonexhaustive, shorter rest periods of 1 min or less can be used without compromising power output (29). The only difference between the BTWL and UTWL is that with BTWL all exercises were performed in a bilateral manner with both arms working in unison to lift the dumbbells in concert instead of unilaterally.

With UCWL all 6 exercises were grouped together and 1 set of all 6 exercises was completed before beginning the next set of all 6 exercises until all 5 sets were completed (e.g., 1 set of bench press was followed by 1 set of bent over row, followed by 1 set of overhead press and so forth until all 6 exercises were completed). The only rest allowed between exercises (~10 s) and sets (~25 s) was the time it took to exchange dumbbells for the next exercise and to the prepare the iPads to collect data for the next set. The only difference between the BCWL and UCWL is that all BCWL exercises were performed in a bilateral manner with both arms working in unison to lift the dumbbells in concert with each other instead of unilaterally. The mean time to complete the workouts was: BCWL (10 min), UCWL (11.9 min), BTWL (29.5 min) and UTWL (32.4 min).

Statistical Analyses

Data were analyzed for statistical significance using JMP Pro 11 (SAS Institute Inc., Cary, NC). Peak power (W) and mean power (W) values for all 6 exercises obtained from the 4 protocols were compared using a mixed model ANCOVA with a $4 \times 5 \times 2$ (group × set × side) blocking on subjects with vertical distance as a covariant and a Tukey's posthoc test as needed.

Results

Peak power (of all lifts combined) was greatest in the UTWL group compared to all other groups ($p < .0001$ for each comparison). No significant differences in overall peak power (all lifts combined) existed between the other 3 groups (Figure 1). Peak power output for the 4 weight lifting protocols and 6 lifts are shown in Table 1. UTWL peak power output was significantly highest for all lifts. UCWL and BTWL generated the second or third highest peak power outputs for all lifts, but they were not statistically different from each other except for the bent over raise. BCWL generated the lowest peak power output in all lifts but was not statistically different from the third lowest peak power output except for the bent over raise.

Mean power (of all lifts combined) was greatest in the UTWL group compared to all other groups ($p < .0001$ for each comparison). No significant differences in overall mean power (all lifts combined) existed between the other 3 groups (Figure 2). Mean power output (see Table 2) was significantly greatest with UTWL for all lifts. UCWL and BTWL mean power output generated the second or third greatest mean power output in all lifts but they were not statistically different from each other except for the bent over raise. The lowest mean power output was with BCWL for all lifts but they were not statistically different from the third lowest mean power output except for the overhead press and the bent over raise.

Significant differences were found in peak power means between UTWL and BTWL in all lifts. UTWL and UCWL peak power was also significantly different in all lifts. In the bench press, bent over row, overhead press, and bent over raise UCWL peak power output was significantly different from BCWL, but there was no significant differences in the bicep curl and front raise. Greatest peak power differences were found between UTWL and BCWL for all lifts. No significant differences were found between UCWL and BTWL in all lifts except the bent over raise. BTWL and BCWL showed no significant differences except for the bent over raise.

Significant differences were found in mean power means between UTWL and BTWL in all lifts. UTWL and UCWL were also significantly different in all lifts. UCWL and BCWL were significantly different in the bench, bent over row, overhead press and bent over raise with no significant differences in the bicep curl and the front raise. UTWL and BCWL displayed the greatest differences on all lifts. BTWL mean power output was significantly greater in all lifts except the bicep curl compared to BCWL.

Discussion

The results of this study support our hypotheses. The main finding of our study was that UTWL generated the highest mean and peak power outputs of the 4 upper body weight lifting protocols tested. Second, our data show that traditional weight training results in the ability to generate greater power output than circuit training. Third, the data support the hypothesis that unilateral weight training can generate greater power output, adding credence to the idea that BLD exists in upper body isotonic exercise. Also, according to the hypothesis, BCWL generated the lowest power output (peak power $p = .0002$, mean power $p = .0001$).

When comparing the traditional weight lifting protocols, UTWL generated significantly greater peak power output (bicep curl $p < .0021$, bent over raise $p < .0004$, all other lifts $p <$

.0001) than BTWL in all lifts. UTWL mean power output was significantly greater (bicep curl $p < .0241$, front raise $p < .0003$, bent over raise $p < .0013$, all other lifts $p < .0001$) than BTWL in all lifts. These results give evidence that BLD exists in upper extremity isotonic lifts, further supporting results from a previous isokinetic study (18).

Most BLD studies are acute studies that utilize isometric contractions (25), isokinetic contractions (13), and dynamic isotonic contractions with machines (16) and show that unilateral contractions generate greater power output than bilateral contractions (18). However, it would be problematic to assume isotonic movements with free weights would produce the same results as studies that utilize isometric contractions, isokinetic contractions, and dynamic isotonic contractions with machines (10). Thus, our study was the first to determine the presence of BLD in dynamic upper body isotonic movements using free weights. This is important because most athletes train with free weights using isotonic movements and not with isokinetic contractions. Therefore, the results of our study could have greater practical application to athletes.

Though the existence of BLD has been well-established in isometric and isokinetic movements, it is not fully understood (3). Previous explanations for the BLD based on physiological and biomechanical aspects have ranged from the subject's level of training and familiarity of the tasks (42), postural stability requirements (23), muscle fiber types (20), to the force-velocity relationship (5). However, the BLD could also be explained on the neurophysiological level based on the theory of neural inhibition (4). Neural inhibition may occur at the spinal level (20) or at the higher order primary motor cortex level (43). It was proposed that if higher order neural inhibition is the major cause of BLD there would be different levels of BLD with different anatomical proximities (3).

Unilateral contractions mainly involve the activation of the contralateral hemisphere of the brain, bilateral contractions involve the activation of both hemispheres of the brain (3). The right and left hemispheres of the brain are connected through the corpus callosum and commissural fibers and provide interactions between homologous cortex areas (4). It has been shown that during bilateral contractions there is a general inhibition effect and decrease in neural drive to the activated muscles resulting in bilateral deficit (27). The number of transcallosal projections connected to proximal muscles are significantly greater than those to the distal muscles (36), so there may be greater interhemispheric inhibition with the proximal muscles than with the distal muscles during bilateral contractions. In contrast, there are less monosynaptic connections between the cortex and proximal muscles than in the distal arm muscles, so there may be less interhemispheric inhibition with the distal muscles than with the proximal muscles during bilateral contractions (3). If the major neural inhibition is at the interhemispheric level, there should be greater BLD at the proximal muscles compared to the distal muscles (3). To test this hypothesis a study was conducted to determine the differences in BLD between isometric shoulder flexion (proximal muscle) and isometric index finger flexion (distal muscle). The results determined that BLD was significantly greater for the proximal muscles than for the distal muscles. This supports the hypothesis that neural inhibition is greater at the interhemispheric level than at corticospinal level, although it is not conclusive and further studies are needed (3).

The importance of understanding BLD in athletics and weight training is that unilateral weight lifting may provide superior training stimuli than bilateral weight lifting because the neural pathways for muscle activation may be more efficient (27). This may yield the ability to produce greater power with unilateral contractions than with bilateral contractions. Additionally most sports involve unilateral movement. Since there are no long-term upper body BLD studies utilizing free weights, evidence that long-term upper body UTWL could produce superior training development than BTWL may be supported by McCurdy, Langford, Doscher, Wiley and Mallard (24) compared the training effect of 8 weeks of unilateral squats and bilateral squats 2 times a week and found that UTWL is more effective in developing lower body power as measured by vertical jump ($p = 0.001$) than BTWL. There is a possibility that the results of this lower body study may apply also to the upper body. Our study examined acute power output of dynamic isotonic upper body free weight contractions and determined that UTWL generates the greatest power output. This supports the argument that long term UTWL will produce optimal development in power because weight lifting protocols that generate maximal power output are most effective in developing muscular power (8). There have not been long-term upper body UTWL studies, so it is unknown if UTWL training is superior to BTWL in developing upper body power, but long-term upper body cross-education studies give evidence that there may be greater strength and power development with UTWL than BTWL (6, 15, 30).

Cross education of strength is the phenomenon that occurs when weight training of 1 limb results in strength gains in the contralateral untrained limb (15, 30, 45). A study was conducted to determine if strength training the free limb would reduce the loss of strength in the contralateral immobilized casted limb (15). After the 3-week intervention, the free-arm training group saw a 23.8% improvement in strength of the trained arm and no significant decrease in strength of the casted arm. The group that did not train the free arm experienced a 14.7% decrease in power output in the casted arm. The results showed that unilateral weight training prevents decreases in strength that are normally associated with an immobilized limb (15).

Another study was conducted with similar groups, but, instead of strength training with isometric contractions, full range of motion elbow flexion with dumbbells was performed (30).

Posttest results showed that the immobilized arm of the training group saw less than 1% reduction in dynamic 1RM in the elbow flexors, while the immobilized arm of the nontraining group saw a 19.8% reduction in elbow flexor strength. Demonstrating again that training of the contralateral limb preserves the strength of the immobilized limb. The study provided the first evidence to the link of maintenance of strength and corticospinal excitability in the immobilized arm as a result of unilateral weight lifting of the contralateral arm (30). These studies may provide an explanation for greater power output in unilateral movement compared to bilateral movement with the possibility that chronic UTWL will create greater corticospinal excitability and therefore could create greater strength and power gains than BTWL. Although cross-education studies and BLD studies give evidence that unilateral weight lifting may provide greater chronic strength and power adaptations than BTWL, further studies need to be conducted to support this supposition.

As stated earlier, our study shows that traditional weight training generates greater power than circuit weight training. Furthermore, BCWL generated the lowest power output in all lifts except the bent over raise. UTWL peak power output was significantly greater than UCWL peak power output for all lifts (bicep curl $p < .0021$, bent over row $p < .0002$, all other lifts $p < .0001$). UTWL mean power output was also significantly greater than UCWL peak and mean power outputs for all lifts (bicep curl $p < .0467$ all other lifts $p < .0001$). This result supports the hypothesis that rest periods less than 1 min will adversely affect power output. Since there are no studies that examine upper body unilateral weight lifting acute power output, we need to compare our results to upper body bilateral studies that examined acute power output utilizing different rest periods.

Ratamess et al. reported the greatest reduction in bench press power output following a 1-min rest as compared to a 3-min rest (32), while Abdessemed et al. found a reduction in bench press power output in 1-min rest periods compared to 3-min and 5-min rest periods (1). In another study, Ratamess et al. reported no reduction in bench press work volume with rest periods of 3-min and 5-min, and the greatest reduction in bench press work volume with rest periods of 1-min and 30 s (33). These studies add support to the evidence of an inverse relationship between rest periods after near-exhaustive sets and the level of muscle fatigue that occurs during ensuing sets.

These previous studies demonstrate that shorter rest periods reduce power and increase fatigue and may offer an explanation as to the reason for the significantly greater power in our study with UTWL compared to UCWL. In our study the rest period between exercises during UTWL was 1 min and during UCWL the rest allowed between exercises was the time it took to exchange dumbbells for the next exercise and get the iPad devices ready for data collection (~10 s between exercises and ~25 s between sets).

Comparisons of the bilateral protocols showed that mean power output was significantly higher in BTWL for the bent over raise (25%), the front raise (19%), and the overhead press (17%) compared to BCWL. Peak power output for BTWL was significantly higher for the bent over raise (28%) compared to BCWL. With the circuit weight lifting protocols, power output was significantly greater during UCWL compared to BCWL in the first three lifts including the bench press (10% peak power, 9% mean power), bent over row (22% peak power, 19% mean power), and overhead press (18% peak power, 16% mean power). But the next 2 lifts, the bicep curl (4% peak power, 10% mean power) and front raise (10% peak power, 13% mean power), showed no significant differences in power output. The last lift in the circuit, the bent over raise, returned back to significantly greater power output (22% peak power, 20% mean power) in BCWL than UCWL.

In conclusion, our study determined that dynamic upper body isotonic unilateral movements generated significantly greater mean and peak power output than dynamic upper body isotonic bilateral movements using free weights. This supports the contention that BLD takes place in upper body isotonic contractions. This was most evident in the traditional weight lifting protocols as UTWL generated significantly greater power output than BTWL for all lifts. It was also concluded that traditional weight lifting protocols generate greater power output than circuit weight lifting protocols. This was most evident in unilateral movements where it was found that UTWL generated significantly greater power output than UCWL in all lifts. It was determined that when using sets with lighter loads and low work volume, rest periods of 1 min did not compromise power output during UTWL, but during UCWL rest periods of less than 30 s displayed significantly reduced power output.

Practical Application

Most athletes weight lift with free weights using bilateral traditional protocols but most athletic movements and skills are not bilateral in nature but require unilateral movements. Our study has determined that unilateral movements with free weights generate significantly greater power output than bilateral movements with free weights. Unilateral weight lifting is also more specific to most athletic movements. Therefore unilateral weight lifting may be more effective in developing power (9), could have a more direct transfer to skill development than bilateral weight lifting (37) and may be the superior method of training performance development.

Although high intensity power training has been shown to develop aerobic capacity and improve body composition (39), our study has shown that traditional weight lifting generated significantly greater power output than circuit weight lifting and supported other studies' findings that shorter rest periods adversely affect power output. Therefore, high intensity circuit training may not be the best way to weight lift when maximal power development is the goal of training, and traditional weight lifting protocols may be the superior method of training. Although our study focused on athletes, the principles of our study are not limited to athletes but may also apply to the general population.

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Table 1: Peak Power Means for each exercise and protocol.

	Protocol	Watts	Std Error	Levels				Protocol	Watts	Std Error	Levels			
Bench press	UTWL	477.4	20.1	A			Bent over row	UTWL	704.3	28.8	A			
	UCWL	417.6	20.1		B			UCWL	572.3	28.8		B		
	BTWL	410.5	20.2		B	C		BTWL	510.8	28.5		B	C	
	BCWL	381.4	20.1			C		BCWL	469.8	29.3			C	
Overhead press	UTWL	474.1	19.9	A			Bicep curl	UTWL	372.3	18.3	A			
	UCWL	379.4	19.9		B			BTWL	329.7	18.1		B		
	BTWL	354.8	20		B	C		UCWL	318.6	18.2		B		
	BCWL	322.2	20			C		BCWL	305.4	18.3		B		
Front raise	UTWL	590.5	24.9	A			Bent over raise	UTWL	799.8	35.5	A			
	BTWL	461.1	24.9		B			UCWL	600.5	36.3		B		
	UCWL	454.5	25		B			BTWL	523.5	35.6			C	
	BCWL	412.7	24.8		B			BCWL	410.5	36.2				D

Levels connected by same letter are not significantly different.

Table 2: Mean Power Means for each exercise and protocol.

	Protocol	Watts	Std Error	Levels				Protocol	Watts	Std Error	Levels		
Bench	UTWL	277.2	11.4	A			Bent over row	UTWL	357.9	12.5	A		
	UCWL	243.5	11.4		B			UCWL	291.1	12.6		B	
	BTWL	240.5	11.4		B	C		BTWL	270.7	12.5		B	C
	BCWL	224.2	11.4			C		BCWL	244.4	12.7			C
Overhead press	UTWL	288.8	11.7	A			Bicep curl	UTWL	166	9.6	A		
	BTWL	222	11.7		B			UCWL	149.2	9.6		B	
	UCWL	220.1	11.7		B			BTWL	147.6	9.6		B	
	BCWL	190.2	11.6			C		BCWL	136	9.6		B	
Front raise	UTWL	230.4	10.2	A			Bent over raise	UTWL	367.1	17.04	A		
	BTWL	189.6	10.2		B			UCWL	264.3	17.38		B	
	UCWL	180.3	10.2		B	C		BTWL	244.7	17.08		B	
	BCWL	159.3	10.2			C		BCWL	195.2	17.33			C

Levels connected by same letter are not significantly different.

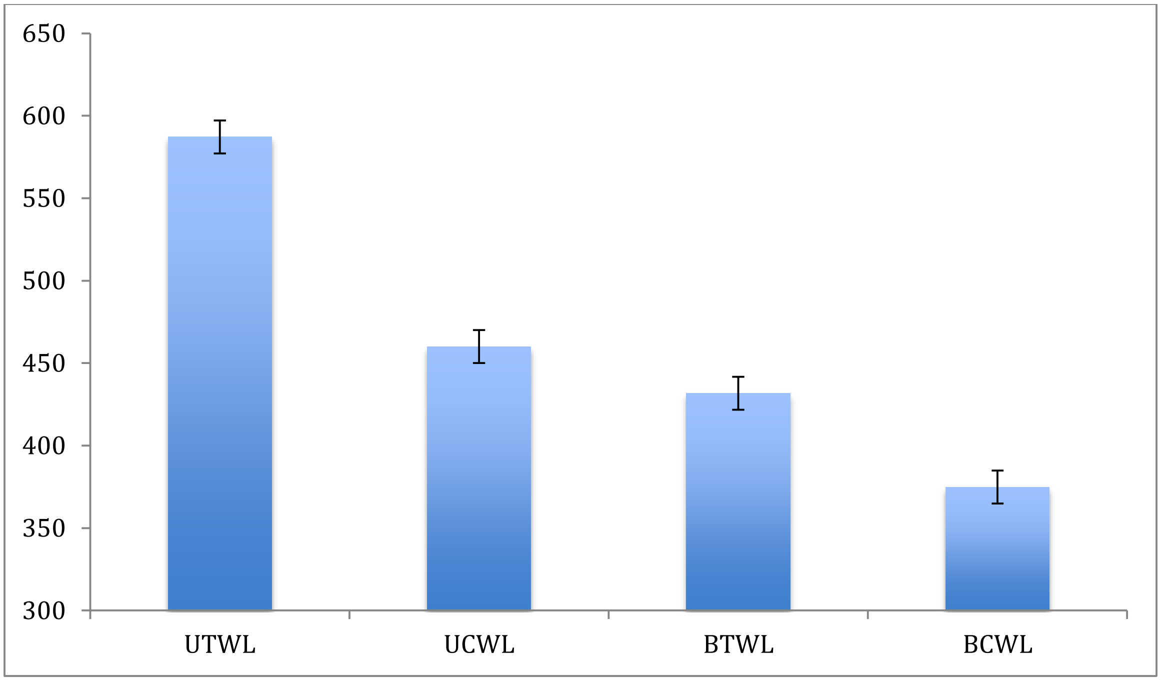

Figure 1: Peak Power Means (W) of all 6 lifts combined for each exercise protocol (for all subjects)

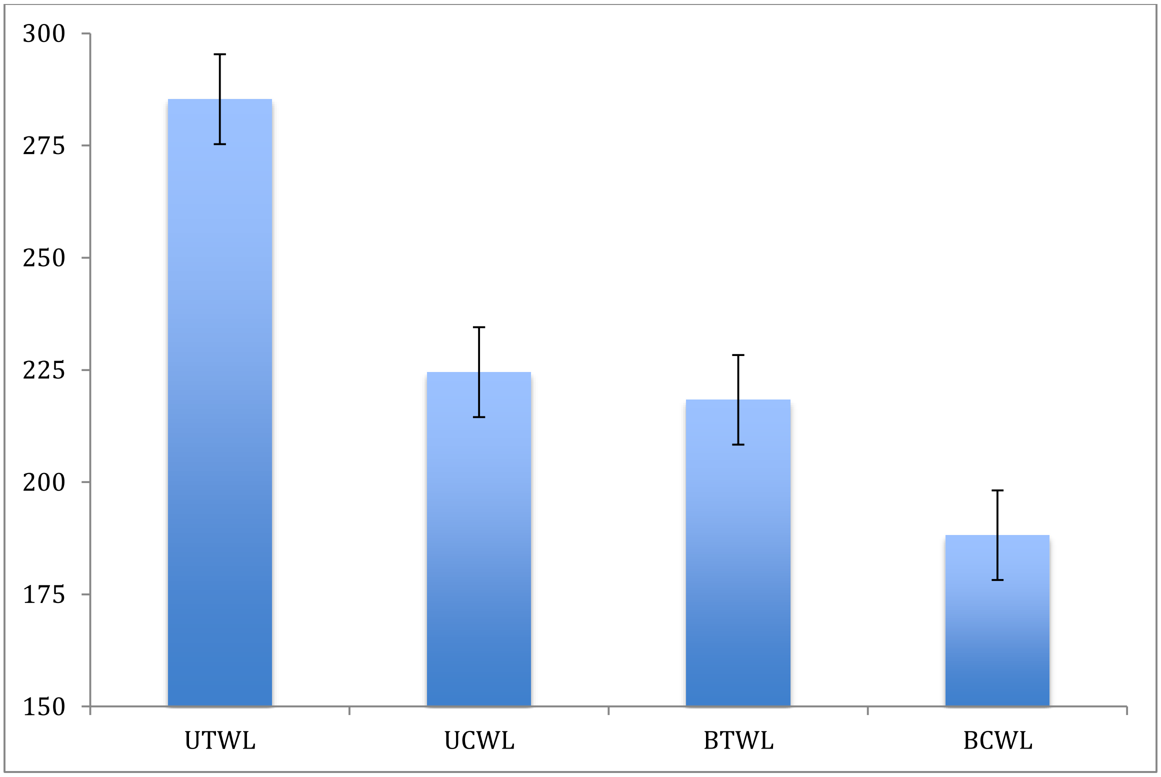

Figure 2: Mean Power Means (W) of all 6 lifts combined for each exercise protocol (for all subjects)