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Original Research Article

Assessing the Impact of Unilateral and Bilateral Resistance Training on Strength Development and Bilateral Index

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Abstract

Purpose: The purpose of this study was to investigate the effects of unilateral (UL) and bilateral (BL) resistance training on muscular strength, bilateral index (BLI), and body composition. **Methods:** Fourteen recreationally resistance-trained individuals (mean ± SD; age = 21.8 ± 2.6 years; BMI = 25.3 ± 3.2 kg/m²) were randomized into UL (n=8) and BL (n=6) groups. The training protocol consisted of two lower-body and two upper-body compound exercises, followed by two lower-body and two upper-body isolation exercises, performed for 3 sets of 6-8 repetitions for compound exercises and 10-12 repetitions for isolation exercises, 3 times per week for 8 weeks. A 2x2 mixed ANOVA was conducted to analyze differences between time points and training groups. **Results:** Pre- and post-intervention assessments included one-repetition maximum (1RM) for UL and BL leg and chest press exercises, BLI, and body composition. Both UL and BL training modalities resulted in significant increases in lower-body muscular strength ($p < 0.01$) and BLI for the leg press ($p < 0.05$), with no significant differences between groups. Upper-body strength improvements were not statistically significant. Body composition changes were similar across groups, though a significant interaction was found for percent body fat reduction ($p < 0.05$). **Conclusions:** These findings suggest that both UL and BL training are effective for enhancing lower body strength and BLI, with comparable effects on body composition. Integrating both modalities into resistance training programs may enhance strength development, address muscle imbalances, and improve overall fitness and performance.

Key Words: Bilateral Deficit, Hypertrophy, Strength Training.

Introduction

The ability to perform at high levels in various sporting endeavors is influenced by numerous physiological factors[1,2]. From a resistance training perspective, two approaches that could be implemented include unilateral training (UL) and bilateral (BL) training[3]. UL training focuses on using one limb or one side of the body at a time, while BL training focuses on using both limbs or both sides of the body simultaneously[3]. Common examples of UL training exercises include single-leg squats, UL chest press, lunges, single-arm row, and Bulgarian split squats, whereas common examples of BL training exercises include barbell squats, barbell bench presses, traditional deadlifts, lat pulldowns, and leg presses.

The use of UL training has been found to be an effective training method to increase muscle strength and performance[4]. Advantages with UL training include improvements in balance and stability as core and stabilizing musculature are recruited when one limb or one side of the body is trained at a time, addressing muscle imbalances between contralateral sides of the body by addressing weaknesses or discrepancies, and aiding in enhancements of functional fitness or sport-specific movements as many real-life activities of daily living and sport-specific movements rely on the use of one limb or side of the body at a time[5,6].

A potential challenge of UL training is that movements are typically done with lower loads as less mass is lifted with UL training compared to BL training[7,8]. The lower resistive load may result in reduced intensity and impede the overload principle[9]. Additionally, UL training may be more time-consuming because the individual must perform exercises on both sides of the body separately, resulting in longer training sessions compared to BL training sessions.

The use of BL training has been demonstrated to be an effective training method to increase muscle strength and performance[10]. Advantages with BL training may include the ability to lift heavier loads as both limbs or both sides of the body are being used to move the resistive load, more efficient training sessions due to both limbs or sides of the body working concurrently, and better muscle synergy with multiple muscle groups engaged at the same time[4,11,12].

A potential challenge of BL training is that muscle imbalances between the contralateral sides of the body may not be addressed[13]. Additionally, muscle imbalances could be augmented if one side is considerably stronger than the other and the individual relies solely on BL training[14]. Another potential challenge of BL training may be limited functional transfer. There are reported concerns about the limited direct transfer of BL training to certain sports or activities that require UL movements[15,16].

Another important challenge of BL training is a phenomenon known as the bilateral deficit (BLD)[17]. The BLD is known as the reduction in force production during BL movements compared to the sum of the forces produced during a UL movement. The BLD refers to the occurrence that when a BL exercise (for example, a two-legged squat) is executed with both limbs together, the total force or strength produced is less than what is produced when the individual forces produced by each limb performing the same movement separately are added together[18].

The purpose of the current study was to investigate the influence UL and BL resistance training have on muscular strength, BLD, and body composition.

Materials and Methods

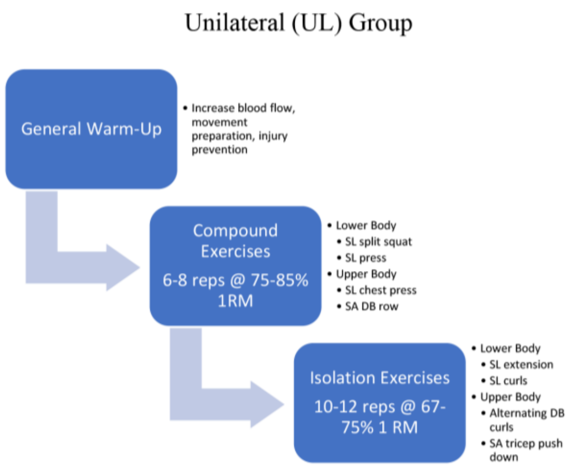
Participants

Participants were recreationally resistance-trained individuals who engaged in resistance training at least two days per week for the previous two months and reported familiarity with the bench press, squat, and deadlift exercise[19]. All participants also needed to be considered "healthy" and could not have any health risks or injuries, which was determined using the Physical Activity Readiness Questionnaire-Plus for Everyone (PAR-Q+). Participants deemed to be recreationally trained and healthy were randomized to BL (n=6) or UL (n=8) training groups. All study protocols and processes were approved by the Institutional Review Board at Minnesota State University, Mankato and followed the principles set forth in the Declaration of Helsinki. All participants provided informed consent prior to participating in the study.

Protocol

A pre and post-test design was utilized with participants randomized to either the UL or BL group. The study began with a baseline assessment protocol, followed by an eight-week training block where participants engaged in whole-body resistance training three days per week, and concluded with post-assessments. The baseline and post-assessment protocol included measurements of height, weight, age, and body composition. One-repetition maximum (1-RM) testing was conducted in the following order: BL leg press, UL leg press, UL chest press, and BL chest press following the National Strength and Conditioning Association's (NSCA) guidelines for muscular strength assessment. A rest period of at least three minutes was used between repetitions and between exercises.

After completing the baseline assessment protocol, participants had at least a 48-hour rest period before beginning the intervention. The training program followed a three-day per week full body split routine, with at least 48 hours between training sessions (Monday, Wednesday, and Friday). The training protocol began with a 5-10-minute low- to moderate-intensity aerobic warm-up, followed by a specific warm-up that included the exercises that would be performed during the session. Compound exercises were placed at the beginning of each session, followed by isolation exercises, which are aligned with the NSCA's recommendations (Figure 1)[19]. The repetitions per set and percentage intensity ranges are based on the NSCA's recommendation for training for muscle hypertrophy, which includes 6-12 repetitions, 67-85% 1RM, and 3 sets per muscle group. The repetition goal for compound exercises was 6-8 repetitions and the repetition goal for isolation exercises was 10-12 repetitions in an attempt to train across various hypertrophy repetition ranges. A rest interval of 60-seconds was used between sets and exercises. Each session included two lower-body compound exercises, followed by two upper-body compound exercises. Next, participants completed two lower-body isolation exercises, followed by two upper-body isolation lifts (Figure 1). The programmed intensity included 75 - 85% 1RM for compound exercises and 67-75% on isolation exercises. The UL and BL groups had training volume matched (sets, repetitions, frequency, and intensity). After each training session, participants consumed a serving of 24 grams of whey protein (NutraOne Nutrition, ProteinOne, Austin, TX).



*** SL: single-leg; SA: single-arm**

Figure 1. Overview of Unilateral and Bilateral training sessions.

Based on executed sets and repetitions, additional load was added to ensure progressive overload week to week. The 2-for-2 rule was used when participants executed two more repetitions than the target repetition range on two consecutive training days[19]. The participants then had an additional 5-10% load added to increase the intensity, thus ensuring progressive overload.

Bilateral index (BLI): An index was calculated as a ratio between BL strength and UL strength aligned with previous work [20]. A BLI was calculated for the chest press and leg press. The BLI is computed as:

$$Bilateral\ Index\ (\%) = 100 \times \left(\frac{bilateral\ strength}{right\ unilateral\ strength + left\ unilateral\ strength}\right) - 100$$

The BL strength is less than the sum of the UL strengths when the index is negative, indicating a BLD. The BL strength is greater than the sum of the UL strengths when the index is positive, indicating a BL facilitation (33, 34).

One-repetition (1RM) maximum test: The 1RM test is considered the gold standard for assessing muscle strength in non-laboratory situations and is defined as the maximal weight that can be lifted once with correct lifting technique [23]. Assessments of 1RM were conducted at baseline and at the conclusion of the 8-week training period using UL and BL leg and chest press machines (Precor Discovery™ Series, Woodinville, WA), following protocols from the NSCA[19].

Body composition: Participants had body composition assessed by bioelectrical impedance (BIA) (Tanita TBF-215, Tokyo, Japan)[24]. The device allows for the assessment of fat free mass (FFM) and fat mass (FM), as well as total body mass. Seven-site skinfold measurements were administered using calipers (Lange Skinfold Caliper, Cambridge, MD) as an additional method to assess body composition and evaluate potential changes in thickness at specific areas of the body. Girth circumference measurements were completed using an elastic tape measure (Gulick II Tape Measure, Gay Mills, WI) and included: abdomen, arm, buttocks/hips, calf, forearm, hips/thigh, mid-thigh, waist. The skinfold and girth measurements followed NSCA protocol and used body density equations from Jackson and Pollock [19,25,26].

Statistical analyses

Statistical analyses were performed using SPSS version 26.0 software (SPSS Inc. Chicago, IL). Data is presented as mean ± standard deviation. Data was examined for normality using the Shapiro-Wilk test. A mixed-model analysis of variance (2 x 2 mixed ANOVA) was used to evaluate the differences between times (pre- and post-training) and training groups (UL and BL). The level of significance was set at $p \leq 0.05$. Partial eta squared (η^2) was used to measure the effect size of different variables in the ANOVA models (small = 0.01, medium = 0.06, and large = 0.14).

Results

Initially, 16 participants enrolled in the study, but after one week of training, two participants in the BL group dropped out due to scheduling conflicts. A total of 14 participants (BL n=6; UL n=8) completed the entire study (mean ± SD; age = 21.8 ± 2.6 years; BMI = 25.3 ± 3.2 kg/m^2). Table 1 displays baseline anthropometric measurements stratified by group. There were no significant differences between groups at baseline.

Right UL leg press 1-RM: There was a significant main effect pre-and post-test for the UL right leg press, $F(1,12) = 21.778$, $p < 0.001$, but there was not a significant interaction between pre-and post-test UL right leg press and the treatment groups (UL) and (BL), $F(1,12) = 0.009$, $p > 0.05$ (Table 2). The partial eta squared was 0.001.

Table 1. Baseline participant characteristics – data are presented as means ± SD.

Training Group	Height (m)	Weight (kg)	BMI (kg/m^2)	Age (yrs)	FFM (kg)	FM (kg)	BIA BF %	7-Site BF %
UL	1.8 ± 0.1	77.8 ± 15.9	25.2 ± 3.3	22.1 ± 3.3	62.4 ± 14.1	15.5 ± 7.4	20.1± 8.6	15.9 ± 10.3
BL	1.7 ± 0.1	74.2 ± 12.5	25.2 ± 3.4	21.8 ± 2.2	56.0 ± 11.7	16.5 ± 5.1	23.0 ± 8	16.6 ± 8.1

UL: unilateral group; BL: bilateral group; m – meters; kg – kilograms; BMI – body mass index; yrs – years; FFM – fat free mass; FM – fat mass; BIA – bioelectrical impedance; BF % – body fat percentage; 7-Site – Jackson Pollock 7 site skin fold
* significant group finding ($p \leq 0.05$)

Left UL leg press 1-RM: There was a significant main effect for pre-and post-test for the UL left leg press, $F(1,12) = 23.792$, $p < 0.001$, but there was not a significant interaction between pre-and post-test UL left leg press and the treatment groups (UL) and (BL), $F(1,12) = 0.248$, $p > 0.05$ (Table 2). The partial eta squared was 0.020.

BL leg press 1-RM: There was a significant main effect pre-and post-test for the BL leg press 1RM, $F(1,12) = 9.916$, $p < 0.01$, but there was not a significant interaction between pre-and post-test BL leg press 1RM and the treatment groups (UL) and (BL), $F(1,12) = 0.041$, $p > 0.05$ (Table 2). The partial eta squared was 0.003.

BL index leg press: There was a significant main effect for pre-and post-test for the BL index leg press, $F(1,12) = 5.451$, $p < 0.05$, but there was not a significant interaction between pre-and post-test BL index leg press and treatment groups (UL) and (BL), $F(1,12) = 0.054$, $p > 0.05$ (Table 2). The partial eta squared was 0.005.

Right UL chest press: There was not a significant main effect for pre-and post-test for the right UL chest press, $F(1,12) = 1.770$, $p > 0.05$, and there was not a significant interaction between pre-and post-test right UL chest press and the treatment groups (UL) and (BL), $F(1,12) = 2.016$, $p > 0.05$ (Table 2). The partial eta squared was 0.129.

Left UL chest press: There was not a significant main effect for pre- and post-test for the left UL chest press, $F(1,12) = 1.180$, $p > 0.05$, and there was not a significant interaction between pre- and post-test left UL chest press and the treatment groups (UL) and (BL), $F(1,12) = 1.854$, $p > 0.05$ (Table 2). The partial eta squared was 0.134.

BL chest press: There was not a significant main effect for pre- and post-test for the BL chest press, $F(1,12) = 1.446$, $p > 0.05$, and there was not a significant interaction between pre- and post-test BL chest press and the treatment groups (UL) and (BL), $F(1,12) = 3.043$, $p > 0.05$ (Table 2). The partial eta squared was 0.108.

BL index chest press: There was not a significant main effect for pre- and post-test for the BL index chest press, $F(1,12) = 1.466$, $p > 0.05$, and there was not a significant interaction between pre- and post-test BL index chest press and the treatment groups (UL) and (BL), $F(1,12) = 0.027$, $p > 0.05$ (Table 2). The partial eta squared was 0.002.

Table 2. Changes in muscular strength. Data are presented as mean ±SD.

	UL		BL	
	Baseline	Post	Baseline	Post
Right UL Leg Press	65.7 ± 29.7	79.9 ± 29.1*	61.3 ± 22.7	74.83 ± 16.2*
Left UL Leg Press	59.5 ± 34.1	79.9 ± 31.3*	61.2. ± 22.7	77.9 ± 17.8*
BL Leg Press	127.1 ± 39.9	146.3 ± 44.5*	120.2 ± 31.3	142.1 ± 32.3*
BL Index Leg Press	8.4 ± 22.3	-6.3 ± 10.3*	5.8 ± 32.2	-6.2 ± 13.1*
Right UL Chest Press	33.7 ± 19.4	33.4 ± 19.9	27.6 ± 13.5	36.3 ± 15.9
Left UL Chest Press	32.9 ± 19.6	32.1 ± 21.1	26.4 ± 13.6	31.1 ± 17.7
BL Chest Press	71.2 ± 39.1	67.8 ± 39.5	58.5 ± 22.7	78.6 ± 39.5
BL Index Chest Press	9.3 ± 7.0	5.1 ± 9.1	17.2 ± 22	11.6 ± 6.5

UL: unilateral group; BL: bilateral group; kg – kilograms;
* significant time finding ($p \leq 0.05$)

Seven-site skinfold: There was not a significant main effect for pre- and post-test percent body fat from seven-site skinfold assessment, $F(1,12) = 0.088$, $p > 0.05$, but there was a significant interaction between pre-and post-test percent body fat from seven-site skinfold assessment and treatment groups (UL) and (BL), $F(1,12) = 5.066$, $p < 0.05$. The partial eta squared was 0.009.

Other body composition and anthropometric measurements: There was not a significant main effect for pre- and post-test with FFM, FM, or any of the eight circumference measurements ($p > 0.05$). There was not a significant interaction between pre- and post-test FFM, FM, or any of the circumference measurements and treatment groups (UL) and (BL) ($p > 0.05$).

Discussion

Resistance training programs can be tailored to individual needs by manipulating training program variables that include exercise selection, order, intensity, volume, rest periods, and frequency. A key aspect of exercise selection may include selecting between BL and UL exercises[27,28]. While the use of both exercise types in resistance training is common, research directly comparing their effects on muscle fitness and performance outcomes is limited. This study aimed to compare the effects of 8 weeks of UL versus BL resistance training on muscular strength, BLI, and body composition. The primary finding of this study is that 8 weeks of UL or BL resistance training resulted in similar improvements in muscular strength, BLI, and body composition.

The current study found that UL and BL resistance training led to maintaining upper-body muscular strength, while lower-body muscular strength improved over the study period, with no differences between UL or BL training groups. These findings align with previous research, such as McCurdy et al. and Botton et al., who reported similar strength gains in untrained individuals and recreationally active women, respectively, using UL or BL training protocols[29,30]. Similarly, Speirs et al. observed no significant difference in strength increases between UL and BL training in rugby players[31] while Jones et al. reported that the pitcher squat (UL movement) had similar hormonal and neuromuscular demands compared to the back squat (BL movement) in a group of resistance-trained college-aged male athletes[32]. The congruency of findings suggests that both UL and BL training modalities are effective for maintaining and enhancing strength in both untrained and trained populations.

Another key finding of the current study was the improvement in the BLI over time regardless of whether UL or BL training was used, while also reporting the existence of a BLD in several exercises[30,33,34]. This finding suggests that both UL and BL training can enhance BLI, which might be particularly relevant for sport-specific applications depending on whether the goal is to maximize UL or BL force production, even though the responsible mechanisms are unclear[35]. The BLD is a phenomenon where the total force produced during BL exercises is less than the sum of forces produced when each limb works independently in UL exercises. While some studies, such as Janzen et al. (2006), reported that BL training reduces BLD more effectively than UL training, the current findings align with Taniguchi's work, which showed beneficial shifts in BLI with both UL and BL training[22,33]. Moreover, studies on young and older adults have demonstrated that heavy BL resistance training and balance training (incorporating UL exercises) can lead to significant improvements in BLI[36]. Incorporating UL exercises into training regimens may help augment BLI, particularly for athletes or individuals aiming to improve UL force production. Taken together, these findings highlight the importance of a balanced approach that includes both UL and BL exercises.

The study's results suggest that incorporating both UL and BL exercises into resistance training programs can increase muscular strength, improve BLI, and positively impact body composition. Identifying and correcting strength imbalances between limbs does appear to be addressed through UL training. For instance, if one leg is significantly weaker than the other, it can be targeted through single-leg exercises like lunges and step-ups. This not only aids in achieving balanced muscle development but also reduces the risk of injury caused by asymmetrical strength. Despite a BLD, BL exercises such as squats, lat pulldowns, deadlifts, and bench presses are essential for building overall strength. These compound movements engage multiple muscle groups and are effective for hypertrophy and neuromuscular adaptation[18]. Over time, consistent BL training can reduce the BLD as the nervous system becomes more efficient at coordinating BL movements.

There is certainly a practical application for including both UL and BL exercises into resistance training programs. A balanced training program that includes both UL and BL exercises can address specific training goals, while maintaining and enhancing strength development[37,38]. This approach ensures comprehensive muscle engagement, addressing both overall strength and specific muscular imbalances[39]. The incorporation of UL training can enhance UL force production and may be beneficial to activities that require asymmetric movements, while the incorporation of BL training can maximize overall strength and power, benefiting activities that rely on BL movements[27].

This study is not without limitations. Not all training sessions were directly monitored, relying on participants' self-reported electronic training logs. Training adherence was high with over 95% of training sessions being completed. Diet was not controlled or assessed, potentially influencing muscle strength and body composition outcomes. Additionally, the study duration was only eight weeks, sufficient to observe changes in muscle strength, considering the participants were recreationally-resistance trained but possibly insufficient for long-term adaptations. Lastly, movement velocity was not controlled in the current study. Participants were instructed to complete the movement with a controlled tempo without an intentional or unintentional fast or slow eccentric or concentric phase.

Future research should explore the long-term effects of UL and BL training on muscular strength, BLI, and body composition. Studies exploring different populations, such as older adults, athletes from different sports, and individuals with varying training backgrounds are warranted. Additionally, investigating different types of resistance exercises and training intensities could provide further insights into optimizing resistance training programs.

Understanding and addressing the BLD is crucial for effective resistance training. By integrating both UL and BL exercises, athletes can develop balanced strength, reduce imbalances, and improve overall performance. This approach ensures a well-rounded training program that maximizes strength and minimizes the risk of injury.

Conclusion

This study suggests that UL and BL resistance training can be effective resistance training strategies to maintain upper-body strength, increase lower-body muscular strength, and improve lower-body BLI in recreationally trained young adults. The findings suggest that both UL and BL training modalities can be integrated into personalized resistance training programs to achieve specific fitness goals.

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