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The Effects of Short-Term Unilateral and Bilateral Lower-Body Resistance Training on Measures of Strength and Power

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Abstract. McCurdy, K., G. Langford, M. Doscher, L. Wiley, and K. Mallard. 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.*—The purpose of this study was to compare the effects of short-term unilateral resistance training (UL) and bilateral resistance training (BL) with free weights on several tests of unilateral and bilateral lower-body strength and power in men and women. Thirty-eight untrained men and women (mean body mass 78.3 ± 21.47 kg; age 20.74 ± 2.6 years) completed the study. The groups trained 2 days per week for 8 weeks with free weights and 2 days per week for 5 of the 8 weeks with plyometric drills. The resistance-training program consisted of a progression from 3 sets of 15 repetitions at 50% of the subject's predicted 1 repetition maximum (1RM) to 6 sets of 5 repetitions at 87% 1RM. Training volume and intensity were equal for each group. The free-weight squat was used to measure unilateral and bilateral strength. Power was measured by the Magaria-Kalamen stair-climb test and the unilateral and bilateral vertical jump test. Analysis of covariance was used to analyze differences between men and women and the interaction of group and gender. Pretest scores were used as the covariate. The UL group improved more than the BL group on the unilateral vertical jump height ($p = 0.001$) and relative power ($p = 0.013$). After adjusting for pretest differences, the improved scores on all tests, except for the unilateral squat, were similar between the men and the women. No significant interactions on all tests were found for the men or women comparison between training groups. These results indicate that UL and BL are equally effective for early phase improvement of unilateral and bilateral leg strength and power in untrained men and women.

Key Words. unilateral vertical jump, bilateral vertical jump, Margaria-Kalamen stair climb, unilateral squat, bilateral squat

Introduction

Unilateral or partial unilateral supported exercises (USE) such as lunges, step-ups, and unilateral squats are implemented in resistance-training programs as assistance exercises and generally receive less emphasis than do core exercises. Although USE are typically integrated into most training programs, the emphasis of utilization varies, in part, because of the lack of scientific data to determine the potential for these exercises to improve strength and power. The exercises are typically used as a variation to bilateral supported exercises (BSE) such as the bilateral squat.

The bilateral squat is typically implemented at the beginning of the resistance-training program to develop a foundation of strength for untrained subjects before using USE. However, many skills that rely on fundamental lower-body movements (running, throwing, hitting, kicking, vertical and horizontal leaps, and changing running direction) are performed entirely or predominantly in a unilateral weight-bearing phase. To most effectively improve performance, resistance exercises should closely resemble the mechanics and forces required to perform the necessary skills in a particular sport (1). Research data are needed to determine if USE could be incorporated early in a resistance-training program to significantly improve strength and explosive power.

Bilateral supported exercises have been extensively investigated to determine the effects of lower-body training on improved strength and power (4, 8, 13–16, 24). Staron et al. (24) investigated time course of muscular adaptations during the early phase (8 weeks of 16 training sessions) of resistance training and found similar improvements in muscle cross-sectional area and relative maximal strength in the bilateral squat and leg press in men and women. Currently, little research data reveal the effects of USE on improved strength and power in men and women. In a cross-sectional design of male and female subjects, Negrete and Brophy (19) found a significant correlation between isokinetic single-leg squat strength at 76 $cm \cdot s^{-1}$ in a weight-bearing stance and single-leg vertical jump height. The Linea isokinetic system that was used in this study measured the force during a concentric phase in a standing position. This measuring system provided an external balance support during the single-leg stance, which could require different muscle recruitment when force is measured in a free-standing position. Using electromyogram analysis, several researchers have found that the hip abductors are recruited in a single-leg stance (no external balance support) for frontal plane stabilization (7, 20, 23). In a group of college-age women, Cordova et al. (5) did not find a significant relationship between isotonic or isokinetic single-leg press strength with rotary motion at $60° \cdot s^{-1}$ and single-leg vertical jump reaction force after 5 weeks of training. The researchers suggested that the strength improvement after non-weight-bearing, closed-kinetic-chain training does not correlate with a change in force on a weight-bearing, closed-kinetic-chain movement.

The effect of free-weight USE on weight-bearing unilateral and bilateral strength and power has yet to be investigated in men and women. Therefore, the purpose of this study was to compare the effect of short-term training with BSE and USE on several measures of unilateral and bilateral strength and power in untrained men and women.

Methods

Experimental Approach to the Problem

To determine if training with USE would significantly increase strength and power similar to improvements after training with BSE, 2 experimental groups were formed: unilateral resistance training (UL) and bilateral resistance training (BL). The UL group trained with USE whereas the BL group trained with BSE. In this experimental design, BSE and USE were implemented as core exercises. After a pretest and 8 weeks of training, a posttest was conducted to determine early phase changes in unilateral and bilateral strength and power in untrained subjects. A distinct approach was to determine if BL improved unilateral strength and power and if UL improved bilateral strength and power.

Subjects

Twenty-three men and 16 women between the ages of 18 and 24 who were enrolled in an entry-level basic-instruction weight-training course completed the study. All the subjects who volunteered to participate were surveyed to determine their training experience. The subjects had not participated in lower-body resistance training within a year before the study. All the subjects signed written informed consent forms that were reviewed by the Institutional Review Board of Valdosta State University to ensure the subjects were knowledgeable of the normal risks and procedures involved in the study. The class was randomly assigned to 2 groups for training: BL and UL.

Testing

Before baseline testing, the subjects were given a 2-week (4 training sessions) instructional period to learn proper technique with loads that approached their 5 repetition maximum (5RM) for the unilateral and bilateral squat. Baseline tests for bilateral and unilateral strength and power were measured during weeks 3 and 4. A rest period with a minimum of 48 hours was provided between each day of testing. Before all tests, subjects were instructed to perform a 5-minute jog as a warm-up exercise and stretch to prevent injury due to testing. All warm-up sets were monitored and the protocol was posted in clear view of the subjects.

Bilateral power was measured with a countermovement vertical jump. Each subject was weighed without shoes and in minimal clothing before the vertical jump test. Vertical jump height, average absolute power, and relative power (average absolute power/mass) produced during the jump were measured with contact timing mats interfaced to a computer (Kinematic Measurement System [KMS] Innervations, Windows 95/98/ME; Skye, Australia). Times were recorded in milliseconds and data were transferred to a computer for analysis. The KMS, which uses total flight times to calculate average absolute power and relative power, has been found to be sensitive indicators of jumping performance with comparison of peak power ($r = 0.88$) and average power ($r = 0.73$) values derived from a force plate (9). Each subject's highest jump of 3 trials and mass were used to calculate average absolute power by the following formula: [$21.2 \times$ jump height (cm)] + [($23 \times$ subject mass (kg)] $- 1{,}393$ (9). The test-retest reliability of this method to determine power in jumping has previously been investigated for the unilateral vertical jump ($r = 0.89$) (21) and the bilateral vertical jump ($r = 0.95$) (3) in untrained subjects. Subjects were instructed to keep their arms on their hips during the vertical jumps to eliminate upper-body momentum (21, 25).

During the strength assessment, each subject followed the procedures while supervised by a researcher. All subjects were measured to attain a 90° angle between the femur and the tibia while performing the squat test. The squat depth was marked and recorded by a measuring device designed to record the depth of the squat for each repetition to ensure that a 90° angle at the knee joint was achieved (Figure 1). For all strength tests, the subjects completed a set of 5–10 repetitions with light weight on the first set with a 1-minute rest period followed by a set of 5 repetitions after adding 10–20% of weight. A 2- to 3-minute rest period was allowed between each successive set. No more than 5 trials were allowed, including the warm-up sets, to attain the 5RM. The 5RM test was used to estimate the 1 repetition maximum (1RM), which was determined by a 1RM prediction chart (18).

The same 5RM protocol used during the bilateral squat was followed to measure unilateral squat depth and strength. Both strength tests were measured by the barbell free-weight squat. While performing the squat, subjects placed the top of their foot of the nondominant leg on a support bar behind them to ensure the dominant leg was the only leg used to perform the squat (Figure 1).

Unilateral power was measured by the Margaria-Kalamen stair-climb test (M-K) and the unilateral vertical jump with a countermovement. All subjects were weighed without shoes and in minimal clothing. The M-K is characterized by a subject sprinting up a staircase of specified height from a specific distance, stepping only on the third, sixth, and ninth steps. KMS contact timing mats were placed on steps 3 and 9. The time started at initial contact with the third step and stopped at contact with the ninth step. Subjects were instructed to complete the sprint up the stairs with maximum velocity. The total power produced during the test was calculated by the following formula: [Power (W) = weight (kg) $\times$ 9.8 ms^{-1} $\times$ distance (m)/time (s)] (11).

Unilateral vertical jump height, average absolute power, and relative power were measured with the same protocol used during the bilateral vertical jump test with the exception of the subjects jumping with the dominant leg only. To isolate the effectiveness of the dominant leg, the subjects were instructed to keep their uninvolved leg inactive under their body (25, 29).

Training Protocol

After the 2-week instructional period and 2-week testing period, both groups followed the resistance-training programs 2 days per week for 8 weeks. Both BSE and USE were implemented as core exercises to maximize strength and power improvement. The core BSE consisted of bilateral squats and front squats, whereas the core USE consisted of unilateral squats, lunges, and step-ups. The UL group performed unilateral squats each session with lunges or step-ups, which were alternated each training session. Training volumes and intensities, based on sets, reps, and percentage of each subject's predicted 1 RM, were equal for both groups. Both programs excluded upper-body exercises to eliminate the possibility of altering the results from potential improvement in upper-body strength or power. Both groups progressed from 3 sets of

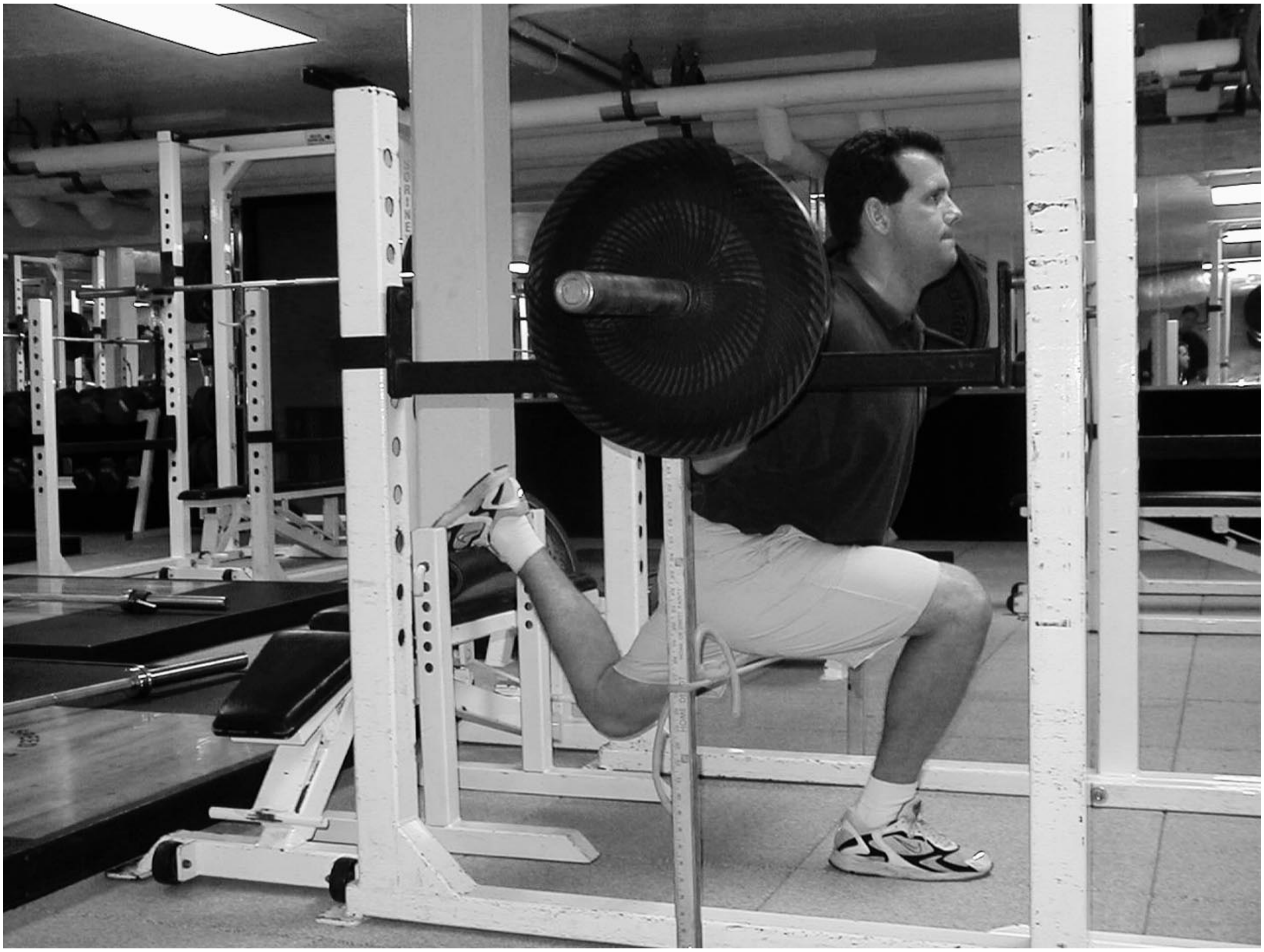

FIGURE 1.

15 repetitions at 50% of each subject's predicted 1RM to 6 sets of 5 repetitions at 87% through the 8 weeks of training. The UL group performed unilateral plyometrics 2 days per week during weeks 3–8, whereas the BL group performed bilateral plyomtrics before the resistance-training session. Each group completed pogo jumps and countermovement vertical leaps each session while progressing from 3 sets of 5 to 3 sets of 15 from week 3 to week 8. The pogo jump was executed with minimal hip and knee flexion upon landing before rebounding vertically for maximum height without the use of the arm swing, and the countermovement vertical leap was completed with a one-half to three-quarters squat. Posttesting was conducted after the 8-week training period with the same protocols as previously described for the baseline tests.

Statistical Analyses

Data were analyzed by 2 × 2 (gender × group) factorial analysis of covariance. Homogeneity of regression assumptions were tested and confirmed before analysis. Posttest scores on all measures were treated as dependent variables, whereas pretest scores were used as the covariate.

RESULTS

The results for the unilateral and bilateral strength were similar. The analysis of posttest measures revealed no main effect for group. After pretest score adjustments, the UL group performance on posttest trials was no different than that of the BL group. For the bilateral squat, no main effect was found for gender. The posttest measures for men were not statistically different from those of women. Although there was main effect for gender on the unilateral squat, the effect size, revealing that the men's scores were significantly higher than the women's scores, was small (partial $X^2 = 0.22$). The interaction between group and gender approached ($p = 0.064$) but did not reach significance. Men benefited no more from UL than they did from BL. Neither was there an advantage for women who trained with USE vs. BSE. The strength results are found in Table 1.

For the bilateral vertical jump test, no main effect was found for training group or gender for vertical jump height, absolute power, and relative power. Unilateral resistance training was no different than double-leg training, and no difference was found in the posttest scores between the men and the women after adjusting for pre-

Table 1. Unilateral and bilateral strength—analysis of covariance posttest measures.†

	Bilateral squat		Unilateral squat	
	Adjusted mean ± *SE*	*p* value	Adjusted mean ± *SE*	*p* value
Training group		<1.0		<1.0
UL	217.16 ± 5.43		140.51 ± 3.64	
BL	224.86 ± 6.20		145.58 ± 4.37	
Gender		0.23		0.004*
Men	228.70 ± 6.67		154.37 ± 4.10	
Women	213.33 ± 8.33		131.72 ± 5.13	
Gender and group		0.064		<1.0
UL men	216.60 ± 8.49		152.59 ± 5.59	
BL men	240.80 ± 8.70		156.15 ± 5.63	
UL women	217.73 ± 10.92		128.43 ± 6.30	
BL women	208.93 ± 10.07		135.01 ± 6.97	

* Statistically significant ($p < 0.05$).
† *SE* = standard error; UL = unilateral resistance training; BL = bilateral resistance training.

Table 2. Bilateral vertical jump test—analysis of covariance posttest measures.†

	Jump height (cm)		Absolute power (W)		Relative power (W·kg^{-1})	
	Adjusted mean ± *SE*	*p* value	Adjusted mean ± *SE*	*p* value	Adjusted mean ± *SE*	*p* value
Training group		<1.0		<1.0		0.269
UL	33.7 ± 1.0		1115.9 ± 29.7		13.8 ± 0.3	
BL	32.7 ± 1.1		1087.8 ± 33.4		13.3 ± 0.3	
Gender		<1.0		<1.0		<1.0
Men	34.1 ± 1.2		1070.2 ± 29.3		13.4 ± 0.4	
Women	32.4 ± 1.4		1133.4 ± 37.4		13.7 ± 0.5	
Gender and group		<1.0		<1.0		<1.0
UL men	34.3 ± 1.2		1095.1 ± 37.6		13.6 ± 0.4	
BL men	33.9 ± 1.9		1045.4 ± 35.1		13.2 ± 0.5	
UL women	33.0 ± 1.7		1136.6 ± 46.9		14.0 ± 0.6	
BL women	31.6 ± 1.8		1130.1 ± 58.2		13.4 ± 0.7	

* Statistically significant ($p < 0.05$).
† *SE* = standard error; UL = unilateral resistance training; BL = bilateral resistance training.

test differences. No interactions were between group and gender. Men benefited no more from UL than they did from BL. Neither was there an advantage for women who trained with USE vs. BSE. The bilateral vertical jump results are reported in Table 2.

The unilateral vertical jump analysis revealed a main group effect for the unilateral vertical jump height ($p = 0.001$) and relative power ($p = 0.013$). The UL group improved significantly more than the BL group on these unilateral variables. The effect sizes for the vertical jump height (partial $X^2 = 0.10$) and relative power (partial $X^2 = 0.17$) were small. Although not significantly different, the UL group improved more than the BL group. No main effects were found for gender on these variables. Men performed no differently than women. No interactions were between group and gender. Men benefited no more from UL than they did from BL. Neither was there an advantage for women who trained with USE vs. BSE. The unilateral vertical jump results are reported in Table 3.

No main effect was found for group or gender on the M-K. Unilateral resistance training was no different than BL, and men performed no differently than the women on the posttest after adjusting for pretest differences. Also, no interaction was between group and gender. Men did not benefit more from UL than they did from BL. There was also no advantage on the M-K for women who trained with USE vs. BSE. The M-K results are reported in Table 4.

The statistical power for the above analyses was quite low. In none of the nonsignificant analyses did the power exceed 0.25. This lack of power is primarily due to the relatively small n for each cell in the factorial design. This lack of power combined with the relatively small effect sizes made it difficult to detect potential group differences.

Discussion

Both training groups similarly improved in unilateral and bilateral squat strength. These results were similar for the men and women in this study. Worrell et al. (28) found significant strength gains in the unilateral seated leg press and improvement in the number of step-up repetitions performed with the body weight plus 25% after 5 weeks of an 8-in lateral step-up training program. This previous study investigated the effects of USE on a non–weight-bearing strength test and on a muscular-endurance step test. In our study, both groups trained and were tested with free-weight exercises. Because our subjects

Table 3. Unilateral vertical jump test—analysis of covariance posttest measures.†

	Jump height		Absolute power		Relative power	
	Adjusted mean ± *SE*	*p* value	Adjusted mean ± *SE*	*p* value	Adjusted mean ± *SE*	*p* value
Training group		0.001*		<1.0		0.013*
UL	18.9 ± 0.5		771.7 ± 43.3		9.5 ± 0.2	
BL	16.2 ± 0.5		751.7 ± 52.3		8.8 ± 0.2	
Gender		<1.0		<1.0		0.170
Men	17.6 ± 0.6		743.1 ± 46.5		9.4 ± 0.2	
Women	17.5 ± 0.7		780.3 ± 57.4		9.0 ± 0.2	
Gender and group		<1.0		<1.0		<1.0
UL men	19.1 ± 0.6		739.8 ± 62.4		9.7 ± 0.2	
BL men	16.0 ± 0.9		746.3 ± 66.5		9.1 ± 0.3	
UL women	18.6 ± 0.8		803.7 ± 69.3		9.3 ± 0.3	
BL women	16.4 ± 0.9		757.0 ± 83.2		8.6 ± 0.4	

* Statistically significant ($p < 0.05$).
† *SE* = standard error; UL = unilateral resistance training; BL = bilateral resistance training.

Table 4. Margaria-Kalamen stair climb—analysis of covariance posttest measures.†

	Power (W)	
	Adjusted mean ± *SE*	*p* value
Training group		<1.0
UL	129.5 ± 2.7	
BL	126.9 ± 3.4	
Gender		<1.0
Men	124.9 ± 3.7	
Women	131.5 ± 4.8	
Gender and group		<1.0
UL men	127.9 ± 4.6	
BL men	121.8 ± 4.7	
UL women	131.1 ± 5.1	
BL women	132.0 ± 6.5	

* Statistically significant ($p < 0.05$).
† *SE* = standard error; UL = unilateral resistance training; BL = bilateral resistance training.

were untrained, we expected to find increased unilateral strength after UL and increased bilateral strength after BL because of the specificity of the training to the testing technique. Untrained subjects have a greater potential to improve their strength (1), particularly when the strength test is performed with the same type of exercise used during training (12).

We also hypothesized that the UL would significantly increase the subjects' bilateral strength but questioned if the BSE group would significantly increase their unilateral strength. Hefzy et al. (10) found that 75% of the resistance is placed on the front leg during a lunge exercise when the knee is flexed approximately 100° and suggested that this exercise might be more beneficial than the 2-legged squat in strengthening the lower body. Although less total weight must be used to perform USE, the single-leg musculature could be working at a high relative intensity that is sufficient for improved strength. Furthermore, during BSE (e.g., 2-legged squat), the contralateral leg provides frontal plane stabilization, which potentially reduces the muscle-recruitment demands from the hip abductors that are active during the single-leg stance (20). Rutherford and Jones (22) concluded that the improvement in the ability to lift weights was due to an increased ability to coordinate other muscle groups involved in the movement used to stabilize the body. We predicted that the strength gained to produce hip and knee extension after BL may not be effectively used in a USE strength test if the frontal plane stabilizers have not been adequately trained. The strength data in this study do not support this speculation when training untrained subjects because no difference between the groups' improvement were found on the unilateral squat. This is the first known study to determine that UL improved bilateral strength and that BL improved unilateral strength. USE and BSE were equally effective in improving unilateral and bilateral strength after short-term training in untrained men and women. More research is needed to determine if similar results are found with a longer training period and with trained subjects. During the assessment of unilateral strength in trained athletes, strength in the stabilizing muscles, such as hip abductors maintaining frontal plane stabilization, may be a greater factor that determines squat strength.

After adjusting for pretest differences between the men and the women on the bilateral squat, no differences were found for strength gains. These data are consistent with previous conclusions that percentage of strength improvement is similar between men and women (24). However, the men significantly improved more than the women on the unilateral squat. The effect size was small (partial $X^2 = 0.22$), indicating that this difference was not robust. Recent studies have reported that differences in kinematics and muscle-group recruitment exist between men and women during a unilateral squat and during the landing phase on a single leg (17, 30). Women have demonstrated difficulty in controlling the hip musculature by allowing more hip adduction, lower hip abductor activity, and more reliance on the knee extensors than do men during the unilateral squat (17). This position places a valgus stress on the knee, which increases the potential for knee injuries. More research is needed to determine if strength gains are comparable between men and women on the unilateral squat. Although beyond the scope of this study, improving unilateral strength may, in part, reduce the number of knee injuries in women.

The UL and BL groups performed both strength and plyometric exercises, which have been shown to be most effective to increase power performance (26, 27). Both training groups similarly improved in the bilateral vertical jump height and absolute and relative power. The improved scores on the bilateral measures were similar for the men and women. These data indicate that improvement of power on bilateral tests is not compromised in the early phase of a resistance-training program when untrained men or women train solely with USE.

The UL group significantly improved more (2.68 cm) than did the BL group in unilateral vertical jump height. Similar results were reported by Delcore et al. (6), who found that unilateral plyometric training was better than BL for increasing unilateral and bilateral vertical jump performance in female volleyball players. With the addition of strength training, our study found similar results in the early phase of a resistance-training program for unilateral vertical jump height and relative power. Although absolute power was higher in the UL group, the lack of a significant difference between groups is likely due to the slight reduction in body mass in the UL group. In a simulation study of the effects of mechanical control and muscle strength on vertical jump performance, Bobbert and Van Soest (2) concluded that athletes need to practice with their changed muscle properties to take full benefit of increased strength. As the BL group's strength improved during the training period, provided practice time on the unilateral vertical jump could have improved the group's ability to use their strength and power on the unilateral jump test. Although the UL group did not practice the bilateral vertical jump, this group significantly improved on this test. Jumping practice could be implemented into the plyometric training drills in similar future research designs.

After adjusting the pretest differences on the unilateral vertical jump test, the improvement of jump height and absolute and relative power were similar between men and women. Although a significant difference was not found for the interaction of group and gender, the men in the UL group improved more than the men in the BL group for jump height (3.12 cm) and relative power (0.56 $W \cdot kg^{-1}$). The men in the BL group performed slightly better than the men in the UL group for absolute power (6.5 W). The women in the UL group improved more than the women in the BL group in jump height (2.23 cm), absolute power (46.7 W), and relative power (0.78 $W \cdot kg^{-1}$). These results for the interaction between gender and group may have been significant with a larger sample size, which is a limitation of the study.

After using pretest scores on the M-K as the covariate, no difference existed between the UL and the BL groups' scores on the posttest. With this statistical analysis, the posttest scores for the men and women were also similar. No advantages were found for the men or women who completed UL or BL. The M-K was included in this study as a unilateral task, which is executed by alternating 1 foot in contact with a step as the subject runs up the stairs. This test for unilateral power is more complex than the unilateral vertical jump test and requires a higher level of skill to perform. The short-term improvement of strength and power from the USE and BSE in this study is likely due to neuromuscular adaptations. The neuromuscular adaptations related to improved performance on the M-K, which possibly occurred in this study, appear to be similar after UL and BL in men and women.

Practical Applications

This study found that the improved bilateral strength and power measures were not significantly different after UL and BL in men and women. With the exception of the unilateral squat, the improvements on all unilateral and bilateral tests were similar between men and women. The small effect size for the difference in the unilateral squat indicates that further investigation is warranted before suggesting that men improve more than women. The data in this study also indicate that USE may be more effective than BSE for improving unilateral vertical jumping performance. USE and BSE were equally effective training protocols to improve early phase performance on the M-K in men and women.

Given that untrained subjects participated in this study, we expected to find improved strength and power on the tests that were similar to the training treatment. The subjects training with USE, when included and treated in the training program as core exercises, were able to increase bilateral strength and power in the early phase of training equal to the subjects who trained with BSE. In untrained subjects, the bilateral squat is the exercise that is typically included in the early phase of the training program to quickly build a foundation of strength before integrating assistance exercises, such as USE. According to our data, incorporating only USE early into the training program does not reduce short-term maximum bilateral strength and power gains in untrained men and women. The data also indicate that USE should receive priority in the early phase of the resistance-training program designed to improve unilateral vertical jumping performance in untrained men and women. Future studies should include resistance-trained athletes and a longer training period to determine if similar results can be found. Differences in strength and power may appear with a longer training period as potential improvement in hypertrophy contributes along with the neurological adaptations to the performance of these tests. Future studies should also be conducted to determine the effect of USE on other sport-specific skills. To improve functional strength and power, strength and conditioning specialists need more data to determine the amount of emphasis that should be placed on implementing USE in their subjects' training programs.

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