

Research article

COMPARISON OF UNILATERAL SQUAT STRENGTH BETWEEN THE DOMINANT AND NON-DOMINANT LEG IN MEN AND WOMEN

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ABSTRACT

The purpose of this study was to compare unilateral squat strength of the dominant and non-dominant leg in young adult men and women. Seventeen apparently healthy men (mean mass 90.5 ± 20.9 kg and age 21.7 ± 1.8 yrs) and 25 women (mean mass 62.2 ± 14.5 kg and age 21.9 ± 1.3 yrs) completed the study. To determine unilateral strength, the subjects completed a one repetition maximum (1RM) modified unilateral squat (MUS) on the dominant and non-dominant leg. The subjects completed the squat to a depth that attained a 90° angle at the knee. This exercise was executed by placing the top of the metatarsophalangeal area of the foot of the uninvolved leg on a support bar behind the subject to isolate the use of the lead leg. Paired samples t-test revealed no significant difference between the men's 1RM mean strength on the dominant (107.0 ± 21.4 kg) and non-dominant (106.0 ± 21.4 kg) leg with a mean side-to-side difference (comparing the stronger to the weaker leg) of 2.8 %. Leg strength symmetry was also found between the women's 1RM mean strength on the dominant (45.3 ± 12.5 kg) and non-dominant (45.0 ± 12.4 kg) leg with a mean side-to-side difference of 5.0 %. The data indicate that unilateral squat strength, measured in a weight bearing stance, is similar in the dominant and non-dominant leg in apparently healthy young adult men and women.

KEY WORDS: Closed Chain, limb symmetry, single-leg strength, unilateral assessment.

INTRODUCTION

Assessment of unilateral leg function is necessary after injury to effectively evaluate and monitor the progress of the client during the rehabilitation process. During rehabilitation, limb strength symmetry is used as an evaluation criterion to determine the level of participation in sporting events and activities of daily living. Range of motion, muscular strength and endurance, and power are also often measured to assess limb symmetry. Non-weight bearing isokinetic testing is a widely used method to measure maximum unilateral strength for strength comparisons between legs.

Non-weight bearing strength testing may not provide sufficient information to predict performance during weight bearing tasks (Pincivero et al., 1997). The inclusion of strength assessment combined with other types of assessment could enhance diagnostic evaluation of lower extremity function. Noyes et al. (1991) reported a 13% increase of subjects diagnosed with abnormal lower limb scores with the addition of a second type of assessment and advised clinicians to always use at least two functional tests with various forms of assessment to evaluate deficiencies. The implementation of a weight bearing unilateral strength test would provide

clinicians with a tool to enhance the side-to-side evaluation of the lower extremity.

The majority of previous studies comparing side-to-side leg strength have found no difference between the dominant and non-dominant leg. Several reliable and valid unilateral tests are currently being utilized to measure leg strength. Isokinetic and isometric strength are commonly measured with an open kinetic chain, single-joint test. Burnie and Brodie (1986) determined that isokinetic knee flexion/extension strength differences did not exist between the dominant and non-dominant leg in preadolescent males. Masuda et al. (2003) found negligible differences between the dominant and non-dominant isokinetic leg strength during knee flexion/extension, hip flexion/extension, and hip abduction/adduction in university soccer players. Neumann et al. (1988) found no difference between right and left isometric hip abduction torque across multiple hip angles in young adult men and women. In contrast to these findings, Hunter et al. (2000) found slightly higher dominant knee extension isometric torque (128.1 ± 3.0 Nm) compared to the non-dominant leg (122.3 ± 3.0 Nm) in 217 women between the ages of 20 and 89 years. These studies measured unilateral strength in a non-weight bearing stance. Measurement of unilateral leg strength in a weight bearing stance could provide the most meaningful information to predict the subject's functional capability due to the specificity between the strength test and weight bearing activities. Results from a weight bearing strength test could be used to help determine the athlete's capability for the return to sport participation or the return of an individual to higher demanding activities of daily living.

Current research has shown that closed kinetic chain exercises place less stress on the anterior cruciate ligament and are often the preferred method of knee rehabilitation (Bynum et al., 1995). In addition, research has shown that low correlations are found between strength gains after training with non-weight bearing exercises and assessment of force produced during a weight bearing test (Cordova et al., 1995). Closed kinetic chain, weight bearing strength tests are considered functional measures since these tests attempt to simulate conditions encountered during lower extremity function. Unilateral leg strength assessed with a closed kinetic chain exercise in a weight bearing stance could be used in addition to the current strength tests available to enhance the diagnostic capability of the clinician.

Assessment of maximum leg strength symmetry in a weight bearing, closed chain exercise is yet to be investigated. The purpose of this study was to compare the strength of the dominant and

non-dominant leg in young adult men and women. Strength was assessed with a modified unilateral squat (MUS) using a barbell with weights as resistance.

METHODS

Subjects

The participants in this study were volunteers from undergraduate classes at Valdosta State University. Apparently healthy young adult men ($N = 17$) and women ($N = 25$) who had no previous pathology in the lower body that would potentially reduce strength performance completed the study. The men's mean body mass and age were 90.5 ± 20.9 kg and 21.7 ± 1.8 years, respectively. The women's mean body mass and age were 62.2 ± 14.5 kg and 21.9 ± 1.3 years, respectively. All subjects were surveyed to determine their training experience. Most men and women had not participated in unilateral or bilateral resistance training prior to this study. A small percentage of the men and women had participated in 6 months to 2 years of continuous bilateral lower body resistance training prior to this study. None of the subjects had previous training experience on the MUS. The subjects had no previous long-term participation in a sport or activities of daily living with high repetitions of asymmetrical lower body activity. All of the subjects signed written informed consent forms that were reviewed by the IRB of Valdosta State University to ensure the subjects were knowledgeable of the normal risks and procedures involved in the study.

Test procedure

Prior to baseline testing, the subjects participated in an orientation session to practice the MUS technique using the bar and the test protocol. During this session, the squat depth of all participants was measured to attain a 90 degree angle between the femur and tibia. The squat depth was marked on a measuring device that was developed by the investigators to record the depth of the squat for each repetition (Figure 1). A resistance band was wrapped around a meter-stick that was anchored to the center of each support bar on the squat rack and set at the height that allowed the subjects' hamstrings to touch the band to attain a 90° angle at the knee. The subjects completed a second practice session of 3 sets of 5-10 repetitions with loads relative to each subject's strength prior to the pre- and posttest.

Pre- and posttests were conducted during the following three weeks. A minimum of 48 hours was allowed between all test sessions (Ploutz-Snyder and Giamis, 2001). Before all tests, the subjects were instructed to perform a 5-minute jog as a warm-up

exercise and stretching exercises to prevent injury. All warm-up sets were monitored by the investigators and the protocol was posted in clear view of the subjects. For all assessments only one leg was tested each session. After completing the pretests on each leg, the subjects repeated the test protocol to complete a posttest on each leg. The posttest data was utilized for analysis.



Figure 1. Modified unilateral squat assessment starting and finish position.

High reliability of the 1RM MUS strength test for trained men ($r = 0.98$), untrained men ($r = 0.99$), trained women ($r = 0.99$), and untrained women ($r = 0.97$) has previously been determined (McCurdy et al., 2004). In this previous study a learning effect occurred from the pre- to posttest but 1RM MUS strength did not improve after a third test session. Ploutz-Snyder and Giamis (2001) concluded that 2-3 strength test sessions are necessary to eliminate the potential for a learning effect. The strength test protocol in this study was designed based on these previous findings.

During the strength assessment each subject followed the procedures while supervised by the same investigators. All subjects completed a 1RM strength test on the dominant and non-dominant leg. For all trials the same investigator monitored the subject's technique while another researcher monitored the depth of the squat. Half of the men and women completed the dominant leg test prior to the non-dominant leg test while half of the subjects completed the non-dominant leg test first. For all strength tests, the subjects completed 5-10 repetitions using light weight on the first set with a one-minute rest period followed by a set of 5 repetitions after adding 10-20% of weight. A 3- to 5-minute rest period was allowed between each successive set. After increasing the weight 20-30%,

the 1RM was attempted on the third trial. For each successful trial 10-20% of weight was added. If unsuccessful, one final trial was attempted after 5-10% of the weight was subtracted. All subjects attained maximum lifts within 6 trials.

The 1RM tests were measured using weights loaded on a barbell. The dominant leg was chosen as the leg used to kick a ball. To test squat strength on the dominant leg, the subjects placed the top of the metatarsophalangeal area of the foot of the non-dominant leg on a support bar behind them to isolate the use of the lead leg (Figure 1). The distance of the pad that supported the uninvolved leg was adjusted closer to or farther behind the subjects to correct for different leg lengths. For a proper starting position, the lead leg is centered in the squat rack approximately 1 inch in front of the measurement band with the leg and upper body in a normal anatomical stance (Figure 2). The knee of the uninvolved leg is flexed at 90° with the hip slightly hyperextended to place the top of the foot on the pad. The investigators observed the subjects' lead leg and the barbell for proper technique. If posterior displacement of the barbell occurred on the descent with no anterior movement of the knee joint, the lift was determined to be unsuccessful. This unsuccessful technique distributes more weight to the uninvolved leg. If excessive trunk flexion was observed and the lead foot was moved during the attempt, the trial was determined unsuccessful. The knee of the lead leg should move anterior approximately level with the lead toes as knee flexion takes place on the descent. For a successful trial the subjects' hamstrings had to touch the resistance band. The same procedure was used to test non-dominant strength.



Figure 2. Modified unilateral squat assessment with subject approaching 90° knee flexion marker.

Statistical analysis

The data were analyzed using SPSS for Windows. Paired-samples t-tests were used to determine if significant differences existed between the dominant and non-dominant leg. The data for the men and women were analyzed separately. The Bonferroni procedure was used to correct for performing multiple t-tests, alpha was set at $p = .03$ for all analyses.

RESULTS

The MUS strength data for the men and women are reported in Table 1. No significant differences were found between the men's and women's dominant and non-dominant leg strength. The men's strength scores ranged from 81.8 kg to 152.3 kg and 79.5 kg to 143.2 kg for the dominant and non-dominant leg, respectively. Dominant strength for the women ranged from 25 kg to 68.2 kg while the non-dominant strength scores ranged from 27.3 kg to 68.2 kg. The men's mean difference was 0.9 kg with a SEM of 1.1 kg for the paired differences. The mean difference between the women's dominant and non-dominant leg strength was 0.3 kg with a SEM of 0.6 kg for the paired differences. Mean side-to-side differences (comparing the stronger leg to the weaker leg) of 2.8 % and 5.0 % were found for the men and women, respectively. Test-retest reliability scores for the men's and women's dominant and non-dominant leg ranged from $r = 0.93$ to $r = 0.99$.

Table 1. Modified unilateral squat strength (kg). Data are means (\pm SD).

Gender	Dominant	Non-Dominant	Difference
Men	107.0 (21.4)	106.0 (21.4)	.9 (4.3)
Women	45.3 (12.5)	45.0 (12.4)	.3 (2.8)

DISCUSSION

Assessment of 1RM leg strength symmetry, measured in a weight bearing stance, can provide valuable assessment data to determine functional strength capacity. In our study, no significant differences in MUS strength were found between the dominant and non-dominant leg in the men (mean difference 0.9 kg) and women (mean difference 0.3 kg). Although Ross et al. (2004) revealed higher dominant isokinetic knee strength than non-dominant leg strength in young adult men and women, the results of this study are in agreement with the majority of previous research that reveals no difference with non-weight bearing strength tests (Hageman et al., 1988). These results are consistent

with more recent studies that found no difference in isokinetic knee flexion and extension average and peak torque between the dominant and non-dominant leg in pre-adolescent and adolescent subjects (Holmes and Alderink, 1984; Mohtadi et al., 1990; Henderson et al., 1993). Similar results were found in isokinetic plantar flexion strength (Damholt and Termansen, 1978), isokinetic knee extension strength (Greenberger and Paterno, 1995; Lindstrom et al., 1995), and isometric hip and knee strength (Neumann et al., 1988) in young adults. These previous studies measured and compared dominant and non-dominant leg strength in a non-weight bearing position with single-joint isolation in an open kinetic chain test, which is not specific to the lower extremity demands during weight bearing activities.

Similar studies have also been conducted on athletes using non-weight bearing strength tests. Masuda et al. (2003) assessed isokinetic hip and knee strength and revealed that no differences between the dominant and non-dominant leg in elite soccer players. Agre and Baxter (1987) and Ostenberg et al. (1998) also found no difference in isokinetic knee extensor strength between the dominant and non-dominant leg in men and women soccer players, respectively. In a recent study, Magalhaes et al. (2004) did not find a significant difference in isokinetic knee extensor strength between the dominant and non-dominant leg in elite volleyball and professional soccer players. In contrast to these findings, a previous study of intercollegiate soccer players revealed significantly higher (7 %) knee torque in the dominant leg (Kramer and Balsor, 1990). Kramer and Balsor (1990) measured average and peak torque with reciprocal concentric-eccentric contraction cycles while similar studies used peak concentric torque, which could account for the difference in the results between these studies of soccer players. The MUS in the present study requires eccentric and concentric strength, but the data in our study does not support that dominant and non-dominant leg strength differences exist with the inclusion of eccentric test demands in young men and women. Kramer and Balsor (1990) suggested that the difference in the volume of activity between the dominant (kicking) and non-dominant leg could produce side-to-side strength imbalance. For every kick and task to control the ball with the dominant leg, the non-dominant leg is active to produce hip and knee flexion and extension in a closed chain skill during a unilateral free-weight bearing stance. The non-dominant leg could be stronger in many soccer players if tested with the MUS due to the specificity between this weight bearing strength test and the high use of the non-dominant leg for weight bearing

support that occurs during many soccer skills. The results of the present study indicate that squat strength, measured in a weight bearing stance, is similar between the dominant and non-dominant leg in young adult men and women who participate in general activities of daily living and are untrained in unilateral exercises.

Muscular strength of the injured leg above 85 % of the uninjured leg is often used as the criterion in sports medicine to allow the athlete to return to full sport participation (Barber et al., 1990). Muscle imbalance between limbs is also thought to be related to an increase risk of injury (Agre and Baxter, 1987). In this study the men's (2.6 %) and women's (5.8 %) mean difference in side-to-side 1RM strength resulted from higher dominant and non-dominant scores. The side-to-side differences in strength varied from 0 to 15.4%. This range of scores justifies a need for more data on young men and women to better develop side-to-side weight bearing strength criterion, which determines the return to pre-injury activity levels of sport and activities of daily living. Young men and women who participate in high intensity sport, recreational and work activities require an accurate and comprehensive evaluation of lower limb function to reduce the risk of further injury after rehabilitation. The side-to-side differences in strength also indicate that pre-injury strength assessment is ideal practice when possible.

Several closed chain machines used to test strength have been shown to produce reliable results (Negrete and Brophy, 2000; Kovaleski et al., 1997). These machines balance and control the resistance which may not be specific to the resistance conditions demanded in a free-weight bearing stance. In a free-weight bearing unilateral stance, hip abduction and adduction muscle activity is necessary to provide frontal plane stabilization (Schmitz et al., 2002). Muscle weakness in the hip musculature may not be adequately assessed using weight bearing machines that provide frontal plane stabilization. Although the MUS is not a complete free-weight exercise with the top of the uninjured foot placed on a support bar, the majority of the barbell weight is supported on the lead leg. Due to a narrow base of support in the frontal plane and a weighted barbell placed on the back, we speculate that the MUS exercise provides less external support than weight bearing squats using machines and is a more functional lower body test for strength.

The most common functional tests of unilateral capability that are utilized during rehabilitation are assessments for muscular endurance and power. Single leg hops for time and distance are tests of power while various tests that include high repetition toe touches in multiple

directions during a unilateral stance are used to assess muscular endurance. These tests are considered functional measures due to the requirement of the activity in a weight bearing stance. Although Greenberger and Paterno (1995) found no difference in a hop test for distance between the dominant and non-dominant leg, Ernst et al., (2000) determined that subjects can demonstrate normal performance on these tests with existing strength deficits. The MUS strength data can be utilized in addition to these results of muscular endurance and power to provide a more comprehensive and accurate evaluation of functional status. Some subjects may decline to complete the hop tests or may not provide maximum effort due to fear of potential pain or injury from the propulsion or landing phase (Barber et al., 1990). The MUS test provides the clinician with an additional functional test as an option for assessment. For athletes that rely primarily on strength for optimum performance, the MUS would be a preferred test in place of the tests for muscular endurance.

As noted, the current strength tests commonly utilized to determine symmetry are single-joint exercises performed in an open kinetic chain. Although these tests are reliable, research shows that low correlations exist between open kinetic chain strength and functional weight bearing performance (Pincivero et al., 1997). With increased emphasis on unilateral weight bearing exercises during rehabilitation, functional weight bearing assessment of maximum leg strength symmetry is warranted.

CONCLUSIONS

Based on the results of this study, dominant and non-dominant 1RM leg strength measured in a weight bearing stance is similar in apparently healthy young adult men and women. This data indicate when strength comparisons are made after injury, similar criterion for the dominant and non-dominant leg can be developed and utilized to determine unilateral capacity using the uninjured leg as the standard in subjects who do not perform high repetitions of asymmetric activity. Some athletes such as soccer players could potentially have leg strength asymmetry induced by leg dominance activity required to perform the sport. Future studies should include athletes as subjects to determine if similar strength results are found with assessment of a unilateral weight bearing test.

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KEY POINTS

- MUS strength was similar between the dominant and non-dominant leg in young adult men and women.
- Mean side-to-side differences (comparing the stronger to the weaker leg) resulted from higher dominant and non-dominant scores for the men and women
- The range of side-to-side differences warrants the practice of weight bearing strength assessment to identify those at risk for injury.

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