

Research article

THE RELIABILITY OF 1- AND 3RM TESTS OF UNILATERAL STRENGTH IN TRAINED AND UNTRAINED MEN AND WOMEN

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ABSTRACT

The purpose of this study was to determine the reliability of the 1- and 3RM tests for the modified unilateral squat. Thirty untrained (22 women, 8 men) and 22 trained (12 women, 10 men) subjects participated in the study. The trained group had a minimum of 1 year lower-body training experience but had not participated in unilateral training prior to the study. After practicing proper technique with light loads, the subjects used the barbell squat to complete a 1- and 3RM pretest and posttest. In each group half of the subjects completed the 1RM tests prior to the 3RM tests while half of the subjects completed the 3RM tests first. A rest period of 48 hours was allowed between each test. Twenty subjects, randomly selected from the two groups, completed a third session of the 1RM test 3 days after the 1RM posttest. Intraclass correlation coefficients were recorded. Differences between pre- and posttest measures were determined by the paired-sample t-test. The 1- and 3RM tests were found to be significantly reliable for trained men, $r = 0.98$ and $r = 0.97$, untrained men, $r = 0.99$ and $r = 0.97$, trained women $r = 0.99$ and $r = 0.94$, and untrained women, $r = 0.97$ and $r = 0.87$, respectively. Posttest scores for the 1- and 3RM tests significantly improved above baseline levels in each group ($p < 0.05$). Strength scores did not significantly increase during the third 1RM test ($p = 0.22$). The data indicate that the modified unilateral squat can be measured with high reliability using the 1- and 3RM tests. The improved posttest scores indicate that a pretest session should take place before recording baseline measurements.

KEY WORDS: Single-leg strength, unilateral squat, resistance exercise

INTRODUCTION

Various tests of lower body unilateral performance are available to determine the baseline function and the effectiveness of a training program. Although one type of exercise may be the primary and preferred method of assessment, research indicates that several measures of lower body performance enhance the ability to assess unilateral leg function (Wilk and Escamilla, 1996). The single-leg hop for distance and time are reliable tests ($r = 0.95$ to 0.96) and widely used in the field of sports medicine

(Bolgla and Keskula, 1997). These hop tests are accepted as a measurement of functional performance due to their specificity to weight bearing activities (Bandy et al., 1994). Unilateral function is commonly measured with open kinetic chain (OKC) dynamometry. Current research suggests that closed kinetic chain (CKC) exercises place less stress on the anterior cruciate ligament and are often the preferred method of knee rehabilitation (Bynum et al., 1995). 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). With the recent increased inclusion of unilateral strengthening exercises in training programs to improve sport performance, prevent injuries and improve rehabilitation, it is necessary to develop reliable, weight bearing unilateral leg strength tests. These tests can be used to measure baseline data and effectively monitor the progress of subjects training with these specific exercises.

Several CKC unilateral tests of muscular endurance are currently used in the field of sports medicine. Loudon et al., (2002) reported high reliability for the step down test ($r = 0.94$), single-leg press ($r = 0.82$), and balance and reach test ($r = 0.83$). These unilateral tests of muscular endurance are performed by completing as many repetitions as possible in 30 seconds. A unilateral CKC strength test could be combined with these valid and reliable measures of muscular endurance to improve the total evaluation of unilateral leg function.

Although hop tests are reliable and considered to be functional tests specific to weight bearing activities, some subjects may not be able to perform these exercises after injury. Rudolph et al., (2000) found that 40% of the non-copers (not able to return to normal activity) were unwilling to complete the hop tests for time and distance fearing that pain or injury would take place. These field tests take little time to conduct and do not require expensive equipment but may not be a useful assessment tool for all subjects. Reliable field tests are needed when other lab tests are not available or practical to administer. Several available field tests are needed to assess subjects who may not be able to complete the suggested test or who may perform below their ability due to the subjects' fear of the test procedure.

In sport conditioning and rehabilitation, the bilateral squat is often used for assessment and training. Verdera et al., (1999) and Blazevich et al., (2002) found high reliability measures, $r = 0.98$ and $r = 0.97$, respectively for the isometric bilateral squat performed in a weight bearing stance. Reliable unilateral tests are required after injury to diagnose deficiencies (less than 85%) in lower limb symmetry (Barber et al., 1990). Suni et al., (1996) determined that the lunge is a reliable test ($r = 0.86$) that could be used for general fitness assessment. A rating scale of 2-5 was used to determine performance after the subjects lifted his or her body weight, 10%, 20 %, or 30% above the individual's body weight, respectively. Few studies have been conducted to analyze the reliability of unilateral leg strength. Kovaleski et al., (1997) measured the reliability of unilateral isokinetic force production at $25 \text{ cm}\cdot\text{s}^{-1}$ ($r = 0.86$), $38 \text{ cm}\cdot\text{s}^{-1}$ ($r = 0.90$), and $50 \text{ cm}\cdot\text{s}^{-1}$ ($r = 0.76$) from a seated leg press machine. Negrete and

Brophy, (2000) tested unilateral squat performance with a Linea isokinetic dynamometer at $76 \text{ cm}\cdot\text{s}^{-1}$ (similar to an angular speed of $180^\circ/\text{s}$) in a weight-bearing stance and found it to be a reliable test for peak force ($r = 0.93$) and average peak force ($r = 0.99$). This system recorded the unilateral force during a concentric phase in a standing position and provided external balance, which differs from the conditions of movement during weight bearing activities. Data from a reliable field test for unilateral strength tested in a weight bearing condition after injury could be compared to the strength of the uninvolved leg and used to evaluate the level of participation the subject is allowed to perform.

A study determining the reliability of an isotonic unilateral strength test performed in a weight bearing stance is yet to be reported. The purpose of this study was to measure the reliability of a modified unilateral squat (MUS) using 1RM and 3RM tests in untrained and resistance trained healthy men and women.

METHODS

Subjects

Thirty untrained (22 women, 8 men) and 22 trained (12 women, 10 men) healthy subjects completed the study. The untrained and trained men's mean body mass and age were $86.31 \pm 18.36 \text{ kg}$ and 21.0 ± 0.76 years and $90.28 \pm 16.53 \text{ kg}$ and 21.60 ± 1.90 years, respectively. The untrained and trained women's mean body mass and age were $62.71 \pm 12.22 \text{ kg}$ and 23.86 ± 6.48 years and $68.44 \pm 11.92 \text{ kg}$ and 21.0 ± 0.85 years, respectively. All subjects volunteered to participate and were surveyed to determine their training experience. The subjects in the trained group had a minimum of one year of lower body resistance training experience prior to the study. Although the subjects had previous resistance training experience, they did not previously train with the MUS exercise used in this study. 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.

Testing

Prior to baseline testing, the subjects participated in an orientation session to become familiar with the MUS technique using the bar and 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 developed by the researchers to record the depth of the squat for each

repetition (Figure 1). The subjects completed one practice session that consisted of performing 5-10 repetitions with light loads. Baseline tests were conducted during the following three weeks. A minimum of 48 hours was allowed between all 1- and 3RM 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 stretch to prevent injury. All warm-up sets were monitored and the protocol was posted in clear view of the subjects.



Figure 1. Modified Unilateral Squat performed at the testing station.

During the strength assessment each subject followed the procedures while supervised by the same researchers. For all trials the same researcher monitored the subject's technique while another researcher monitored the depth of the squat. The trained and untrained men and women were randomly divided into two groups. Half of the subjects completed the 1RM tests prior to the 3RM tests while half of the subjects completed the 3RM tests prior to the 1RM test. 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 1- or 3RM was attempted on the third trial. For each successful trial 10-20% of weight was added. If unsuccessful, one trial was attempted after 5-10% of the weight was subtracted. All subjects attained maximum lifts within 5 trials. No more than 5 trials were allowed including the warm-up sets to attain the 1- or 3RM. The 3RM test could be used to estimate the 1RM using a 1RM prediction chart (Morales and Sobonya, 1996).

Both strength tests were measured using the barbell free-weight squat. The dominant leg,

determined to be the leg used to kick a ball, was selected to perform the lift. While performing the squat, participants placed the top of the foot of the non-dominant leg on a support bar behind them to insure the dominant leg was isolated to perform the squat (Figure 1). The researchers 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 technique distributes more weight to the uninvolved leg.

Table 1. 1- and 3RM test of untrained subjects. Data are means (\pm SD).

	Test 1 (kg)	Test 2 (kg)	ICC
Men			
1RM	85.8 (0.0)	88.64 (18.5)	.99*
3RM	74.7 (5.6)	80.40 (16.0)	.97*
Women			
1RM	44.0 (9.9)	45.76 (10.7)	.97*
3RM	35.9 (10.4)	39.77 (10.4)	.87*

* significant $p \leq 0.05$

Statistical analyses

The data were analyzed using SPSS for Windows. Intraclass correlation coefficients were calculated to determine the test-retest reliability of the strength tests. Paired-samples t-tests were used to determine if significant differences existed between the test-retest measures. After finding that a learning effect occurred during the retest, a third strength test was conducted. A p value of ≤ 0.05 was accepted as the level of statistical significance for all analyses.

RESULTS

Means (\pm SD), ICC, and SEM values for the 1- and 3RM tests with untrained men and women are presented in Table 1. The trained subjects' means (\pm SD), ICC, and SEM values for the 1- and 3RM tests are presented in Table 2. The third test data for the 1RM squat, completed by the group of trained and untrained subjects, are presented in Table 3. The correlation coefficients ranged from $r = 0.87$ to $r = 1.0$. Power for all tests ranged from 0.59 to 1.0.

Table 2. 1- and 3RM test of trained subjects. Data are means (\pm SD).

	Test 1 (kg)	Test 2 (kg)	ICC
Men			
1RM	114.6 (17.9)	121.6 (17.7)	.98*
3RM	98.6 (21.5)	103.0 (21.5)	.97*
Women			
1RM	54.2 (11.7)	55.3 (11.6)	.99*
3RM	44.1 (10.2)	47.5 (8.6)	.94*

* significant $p \leq 0.05$

Mean differences between test-retest scores are reported in Table 4. Significant differences were found between test 1 and 2 for the trained and untrained men and women on the 1- and 3RM tests. No significant difference between the means were found during the third test on the 1RM test ($p = 0.22$).

Table 3. 1RM test 3. Data are means (\pm SD).

	Test 2 (kg)	Test 3 (kg)	ICC
1RM	63.2 (31.3)	64.0 (31.2)	1.00*

* significant $p \leq 0.05$

DISCUSSION

No known studies have reported the reliability of a unilateral strength test in a free weight bearing stance. Several unilateral tests performed in a free weight bearing stance (step down and balance and reach) are used in the field to assess muscular endurance. The reliability of the lunge has previously been investigated. During the repetition of a lunge, hip and knee flexion and extension are performed with a narrow lateral base of support, which is similar to the mechanics required to complete the MUS. In a previous study using the subjects' body weight with strength increments of 10%, 20% and 30%, Suni et al. (1996) concluded that the lunge was a reliable test of general strength that could be used in a health-related fitness test battery for adults. While executing the lunge, approximately 75% of the weight is supported on the lead leg (Hefzy et al., 1997). The technique of this exercise can vary by distributing more weight on the back leg during training and testing. Although beyond the interpretation of the data in this study, we speculate that a higher percentage of the weight is supported on the lead leg of the MUS with little capability to support the weight on the back leg. With the top of the back foot on the supporting pad, the subject's ankle joint does not have the capacity to support high loads. To ensure that a low percentage of the weight was distributed to the uninvolved leg, the anterior-posterior displacement of the bar was monitored.

The MUS could be used as a reliable CKC test and as an exercise for training. Best practice is to test subjects with a similar exercise that was used during training (Worrell et al., 1993). The lateral step-up and unilateral leg press are commonly used in training while an OKC isokinetic test is used to assess knee function. While the OKC offers valuable force capability from the isolation of a single joint, the MUS provides strength data measured in a weight bearing stance. The OKC and CKC measurements can collectively be used to evaluate

the subjects' ability to return to normal activities or sport participation.

Hop tests are also considered functional tests and commonly used to detect unilateral functional limitations. Although these tests offer reliable and valuable results, Ernst et al., (2000) found that subjects can demonstrate normal performance with existing strength deficits. The subjects in this previous study utilized the hip and ankle joints to compensate for the strength deficit at the knee. Assessment of unilateral strength is warranted to confirm the interpretation of normal results from the hop tests. Noyes et al., (1991) reported a 13% increase of subjects diagnosed with abnormal lower limb scores when a second test was conducted and advised clinicians to always use at least two functional tests with various forms of assessment to evaluate deficiencies. In addition, some subjects may decline to complete the hop test or may not provide maximum effort due to fear of potential pain or injury from the propulsion or landing phase (Barber et al., 1990). Alkjaer et al., (2002) reported reduced levels of eccentric loading during knee flexion of the lunge compared to the loads found during the hop tests. With no impact phase needed to complete the MUS, it is likely that low levels of eccentric loading, similar to the loads found to complete a lunge, are placed on the joints. While completing the MUS, non-coping subjects may not demonstrate the apprehension previously reported during the single leg hop tests, and therefore provide maximum effort.

Table 4. Mean differences between tests.

	Mean Diff (\pm SD) (kg)	SEM
Untrained Men		
1RM	2.84 (3.15)	1.11*
3RM	5.68 (3.65)	1.29*
Trained Men		
1RM	7.05 (3.78)	1.20*
3RM	4.32 (5.30)	1.68*
Untrained Women		
1RM	1.75 (2.64)	.56*
3RM	3.93 (5.30)	1.13*
Trained Women		
1RM	1.14 (1.53)	.44*
3RM	3.41 (3.29)	.95*
Trained and Untrained 1RM	.80 (2.79)	.62

Results are reported between test 2 and 3 for the combined group of trained and untrained subjects. Every other result is reported between test 1 and 2.

* significant $p \leq 0.05$

Unilateral assessment of maximum (1RM) or near maximum (3RM) strength is typically not

recommended due to reliability and safety considerations (Baechle et al., 2000). The inability to maintain proper posture during a unilateral squat may reduce reliability and increase the risk of injury. The results of this study do not support this speculation. No injuries occurred during the study. In this study the top of the subjects' uninjured foot was placed on a supporting pad to improve the balance required to perform the MUS. The distance of the supporting pad behind the subject was adjusted to maintain hip extension of the uninjured leg during the squat. While practicing the technique to maintain proper posture, the subjects were instructed to maintain an upright posture and position the lead knee above the toes at the bottom of the squat. If improper technique was observed, the trial was determined unsuccessful. The ability of the subjects to maintain proper posture did not appear to be the limiting factor for a successful attempt.

One and three repetition maximum tests are generally not recommended for untrained subjects, particularly for the bilateral squat. Untrained subjects may not have the ability to complete the bilateral squat using proper technique with relatively high absolute loads on the spine and lower body, which could reduce reliability and increase the risk of injury. When subjects can use proper technique, accuracy for predicting maximum strength increases as loads approach 1RM (Morales and Sobonya, 1996). Compared to the bilateral squat, lower absolute loads are placed on the spine and joints of the lower body during the MUS. The results of this study indicate that trained and untrained men and women can safely complete the MUS using 1- and 3RM loads with reliable results.

The subjects' mean strength for both groups of men and women improved during the retest, which indicated a learning effect occurred. These data are similar to the results from a study by Ploutz-Snyder and Giamis, (2001) who found that 3 testing sessions are required to attain consistent 1RM isokinetic knee extension strength measurements in young women. In our study mean strength scores did not improve after a third 1RM test was administered to a random sample of trained and untrained subjects. The random sample was chosen from all groups to complete the 1RM test since all groups revealed similar results on the first and second test for the 1- and 3RM tests. Prior to testing the subjects should be provided time to practice the technique with light weight. After an orientation session and practice with light loads, the subjects should also complete a pretest prior to the test session to practice proper technique while becoming familiar with maximum or near maximum loads to obtain an accurate measurement of strength.

CONCLUSIONS

The test-retest measures of the MUS were found to be highly reliable for the 1- and 3RM tests performed by the trained and untrained men and women. Reliable, functional strength tests are valuable assessment tools for sport conditioning and rehabilitation. The MUS is a functional test that closely resembles the weight bearing movement characteristics of many sport skills and activities of daily living. Many sport skills are performed completely or partially supported on a single leg (Tillman et al., 2004). After injury, the subject's goal is to rehabilitate the injured leg close to the capability of the uninjured leg before resuming higher demanding activities of daily living and sporting events. Coaches and clinicians can compare unilateral strength measurements between the injured and healthy leg and combine these measures with other forms of assessment to prescribe the subject's level of activity. The data indicates that coaches and clinicians can utilize the MUS as a field test to reliably monitor the progress of unilateral strength in healthy trained and untrained men and women. The MUS could be used to assess initial levels of strength for the prescription of training intensity and to determine strength gains after a period of training with similar unilateral exercises. Similar studies in future research should include athletes and subjects with preexisting injuries with comparison of measurements between the dominant and non-dominant leg.

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KEY POINTS

- The modified unilateral squat is a reliable test for trained and untrained men and women.
- The 1RM and 3RM tests are reliable and safe for trained and untrained subjects.
- A practice session and pretest should be conducted prior to baseline testing.

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