THE RELATIONSHIP BETWEEN MAXIMUM UNILATERAL SQUAT STRENGTH AND BALANCE IN YOUNG ADULT MEN AND WOMEN

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ABSTRACT

The purpose of this study was to determine the relationship between unilateral squat strength and measures of static balance to compare balance performance between the dominant and non-dominant leg. 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. Weight bearing unilateral strength was measured with a 1RM modified unilateral squat on the dominant and non-dominant leg. The students completed the stork stand and wobble board tests to determine static balance on the dominant and non-dominant leg. Maximum time maintained in the stork stand position, on the ball of the foot with the uninvolved foot against the involved knee with hands on the hips, was recorded. Balance was measured with a 15 second wobble board test. No significant correlations were found between the measurements of unilateral balance and strength (r values ranged between -0.05 to 0.2) for the men and women. Time off balance was not significantly different between the subjects' dominant (men 1.1 ± 0.4 s; women 0.3 ± 0.1 s) and non-dominant (men 0.9 ± 0.3 s; women 0.3 ± 0.1 s) leg for the wobble board. Similar results were found for the time balanced during the stork stand test on the dominant (men 26.4 ± 6.3 s; women 24.1 ± 5.6 s) and non-dominant (men 26.0 ± 5.7 s; women 21.3 ± 4.1 s) leg. The data indicate that static balance and strength is unrelated in young adult men and women and gains made in one variable after training may not be associated with a change in performance of the other variable. These results also suggest that differences in static balance performance between legs can not be determined by leg dominance. Similar research is needed to compare contralateral leg balance in populations who participate in work or sport activities requiring repetitive asymmetrical use. A better understanding of contralateral balance performance will help practitioners make evaluative decisions during the rehabilitation process.

KEY WORDS: Single-leg strength, closed kinetic chain, unilateral balance, resistance exercise.

INTRODUCTION

The relationship between balance and strength has been notably investigated to prevent falls and injury in the elderly and to improve rehabilitation procedures. Blackburn et al. (2000) reported that strength contributes to balance by producing muscle stiffness (resistance to muscle lengthening), which could enhance neuromuscular control by increasing proprioceptor sensitivity to stretch and reducing electromechanical delay from the muscle spindle stretch reflex. A better understanding of the factors associated with balance performance in other populations is needed in order to develop training programs for those with balance deficiencies. More data are needed to better understand the amount of

variance in balance performance that can be predicted from the variability in unilateral weight bearing strength.

The majority of previous studies have been conducted to analyze the effect of muscle strength on static and dynamic balance performance in populations with significant muscle weakness. These studies have utilized elderly (Carter et al., 2002), post stroke (Kligyt et al., 2003), and osteoporosis (Lord et al., 2002) subjects to determine the relationship between strength and balance but results have varied. These inconsistent findings may be a result of variations in research design including the measurement of strength and balance with different methods of assessment. Most of these studies have analyzed strength with open kinetics chain (OKC) tests while assessing balance in a closed kinetic chain (CKC) stance. Non-weight bearing OKC and CKC resistance training methods have also been implemented to investigate the effect of improved strength on balance performance (Blackburn et al., 2000; Kalapotharikos et al., 2004; Mattacola and Lloyd, 1997; Vanderhoek et al., 2000; Verfaillie et al., 1997). Further research investigating functional tests of strength measured in a weight bearing stance is needed to better determine the relationship between strength and balance.

No known studies have analyzed the relationship between unilateral balance and 1RM strength measured in a weight bearing stance. Weight bearing strength assessment arguably best estimates the functional status of the lower extremity due to its specificity with weight bearing tasks. Few studies have investigated the relationship between balance and strength in apparently healthy young adults. The relationship between strength and balance may differ in young adult and elderly subjects due to differences in strength between the groups.

Few studies have analyzed the difference in balance between the dominant and non-dominant leg (Hoffman et al., 1998). Side-to-side differences that may be common could affect the individual's balance during different unilateral and bilateral weight bearing tasks, which could increase the risk of injury. Research revealing significant differences between the dominant and non-dominant leg would support assessment prior to participation in high intensity activity to detect balance asymmetry and training to improve deficiencies and reduce the risk of injury. After injury, balance tends to be reduced in the injured leg due to loss of proprioceptor function (Katayama et al., 2004). During rehabilitation, balance assessment is common to make evaluations using the uninjured leg as the standard for comparison. More data is needed to determine if balance symmetry exists between the dominant and non-dominant leg prior to injury to accurately evaluate lower limb function while using the uninjured leg as the criterion.

To further understand the relationship between unilateral balance and strength, both variables should be investigated with measurements from weight bearing tasks to closely achieve specificity between the test demands. Therefore, the purposes of this study were to determine: 1) the relationship between maximum unilateral squat strength and balance on the stork stand and computerized wobble board and 2) the difference in balance between the dominant and non-dominant leg.

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 injuries to the hip, knee, or ankle that would potentially reduce strength or balance 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 modified unilateral squat (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. The students were surveyed for this ambidextrous ability that potentially could develop in sports such as soccer to ensure that they did not have advanced motor skills related to the tests that were performed. All of the subjects signed written informed consent forms that were reviewed by the IRB of Valdosta State University.

Modified Unilateral Squat Test
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 a height to attain a 90º angle at the knee when the subjects' hamstrings touched the band (Figure 2). 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. High reliability has been found recently for the MUS performed by trained and untrained men and women during 1- and 3RM tests (McCurdy et al., 2004).

repetitions using 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 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.

Figure 1. Starting position of the unilateral squat.

Figure 2. Measurement of the 90º angle at the knee to complete the descent of the unilateral squat.

Pre- and posttests were conducted during the following three weeks. A minimum of 48 hours were allowed between all test sessions. Before all tests, the subjects were instructed to perform a 5-minute jog as a warm-up exercise and stretch. 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 to account for strength improvement due to a learning effect of the strength assessment (Ploutz-Snyder and Giamis, 2001).

All subjects completed a 1RM strength test on the dominant and non-dominant leg. 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

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 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 1). The same procedure was used to test non-dominant strength.

Balance tests
The stork stand and the Kinematic Measurement System (KMS) (Fitness Technology, Skye, Australia) were used to measure balance. For the stork stand the subjects completed the test on the dominant and non-dominant foot. The subjects kept

Table 1. Mean strength and balance descriptives. Data are means (±SEM).

		Strength (kg)	Wobble Board (seconds off balance)	Stork Stand (seconds)
Men	Dominant	107.0 (5.2)	1.1 (.4)	26.4 (6.3)
	Non-Dominant	106.0 (5.2)	.9 (.3)	26.0 (5.7)
Women	Dominant	45.3 (2.5)	.3 (.1)	24.1 (5.6)
	Non-Dominant	45.0 (2.5)	.3 (.1)	21.3 (4.1)

their hands on their hips with the uninvolved foot against the medial side of the knee of the stance leg. Each subject maintained this position while standing on the ball of the foot for the maximum possible time. The trial ended when the heel of the involved leg touched the floor, the hands came off of the hips, or the opposite foot was removed from the stance leg. The best of three trials was recorded for analysis.

Table 2. Wobble board and strength correlations.

		r value
Men	Dominant	- .02
	Non-Dominant	.20
Women	Dominant	- .05
	Non-Dominant	.09

The subjects also performed the wobble board test in a unilateral stance on their dominant and non-dominant foot. The KMS utilizes a wobble board that is interfaced with a computer, which records the data. With the shoes off, the subjects stood on the center of the wobble board with the hands on the hips and the uninvolved foot free to move in space. During a 15 second period, each subject attempted to maintain balance without allowing the board to touch the contact plate that was positioned on the floor 2 inches under the wobble board. The subjects were instructed to regain their balance as quickly as possible when the wobble board touched the contact plate. Within the 15 second period, the duration the wobble board touched the contact plate (time off balance) was recorded for analysis. If the uninvolved foot touched the floor or wobble board to regain balance, the trial was repeated. The least duration of time off balance during the 15 second period after 3 trials was analyzed.

Table 3. Stork stand and strength correlations.

		r value
Men	Dominant	-.06
	Non-Dominant	.08
Women	Dominant	.32
	Non-Dominant	.34

Statistical analyses
The data were analyzed using SPSS for Windows. Pearson product moment correlations were calculated to determine the relationships between balance and strength tests. A *p* value of ≤ 0.05 was accepted as the level of statistical significance for the correlation data. To determine significant differences between the dominant and non-dominant leg, the Bonferroni procedure for performing multiple t-tests was utilized to set at a *p* value of ≤ 0.01. The men and women data were analyzed separately.

RESULTS

Mean and standard error unilateral strength and balance data are reported in Table 1. Correlations between balance on the wobble board and strength are shown in Table 2. No significant correlations were found between balance on the wobble board and strength on the dominant and non-dominant leg for the men and women. Correlations between stork stand balance and strength are shown in Table 3. No significant correlations were found between the balance scores on the stork stand and strength scores on the dominant and non-dominant leg for the men and women. Balance performance was not significantly different between the dominant and non-dominant leg for the men's and women's stork stand and wobble board scores (Table 4). The men's (22.3 ± 16.3 %) and women's (24.9 ± 16.0 %) mean side-to-side differences on the stork stand were higher than the differences on the wobble board for the men (4.5 ± 4.9 %) and women (2.5 ± 3.1 %).

Table 4. Dominant and non-dominant balance. Data are means (SEM).

		Dominant-Non-dominant Difference (sec)
Wobble Board	Men	.2 (.2)
	Women	.0 (.1)
Stork Stand	Men	.5 (2.8)
	Women	2.7 (2.5)

DISCUSSION

The results of this study revealed that unilateral balance performance was not associated with 1RM squat strength performance. Although the MUS is performed with reduced frontal plane base of

support, the data indicate that strength performance is not related to unilateral balance measures. The potential differences in muscle stiffness due to differences in strength may not be associated with differences in static balance performance.

In contrast to previous studies, CKC strength and balance were measured in a weight bearing stance on the dominant and non-dominant leg. Previous studies reveal inconsistent findings in the relationship between strength and balance. Our data agree with Ringsberg et al. (1999) and Kligyt et al. (2003) but differs from the results of a study by Carter et al. (2002) and Binda et al., (2003) who found a significant relationship between strength and balance. Ringsberg et al. (1999), Carter et al. (2002), Binda et al. (2003), and Kligyt et al. (2003) assessed isometric strength with non-weight bearing tests in OKC conditions to analyze the relationship between strength and balance while Heitkamp et al. (2002) assessed isokinetic strength. Heitkamp et al. (2001) found improved 1-leg standing balance performance after seated leg press training but found no change in 2-leg balance scores on a stabilometer in young adult men and women. The development of a consensus on the relationship between strength and balance should be made with consideration of the specificity between the strength and balance tests. A low relationship exists between OKC and CKC strength and between OKC strength and performance in weight bearing tasks (Vanderhoek et al., 2000). Comparisons are made in previous studies between non-weight bearing strength and weight bearing balance in a variety of unilateral and bilateral tasks (Bohannon 1995; Lord et al., 2002). Our study measured CKC strength and balance in a weight bearing stance.

Several studies have shown that strength training improves balance (Heitkamp et al., 2001; Kalapotharikos et al., 2004; Pintsaar et al., 1996) while other studies have reported that balance training improves strength (Heitkamp et al., 2001; 2002). In contrast to these results, Wolfson et al. (1993) and Verfaillie et al. (1997) reported no change in balance performance after resistance training. With the exception of one study of experienced judokas (Heitkamp et al., 2002), untrained, sedentary, and elderly subjects with low initial levels of strength participated in these investigations. It is possible that a significant relationship exists between strength and balance in subjects who demonstrate muscle weakness, and as a minimum threshold of strength is attained, the relationship between strength and balance may be attenuated. The subjects in this study were recreationally active young adult men and women and most likely stronger than the subjects in similar

previous studies although direct comparisons cannot be made due to the different methods used to assess strength. The data in this study indicate that strength and static balance, measured in a weight bearing stance on the dominant and non-dominant leg, are not related in apparently healthy young adult men and women. Gu et al., (1996) previously found that joint torques required to maintain and regain balance on tests with platforms that produce perturbations are well below the strength capabilities of healthy young and older adults. This finding may, in part, explain the lack of relationship between strength and balance found in this study. More data is needed to determine if MUS strength is related to dynamic balance measures, particularly activities with higher loading conditions such as jump-landing tasks.

The lack of relationship between strength and balance could be due to difference in muscle groups that are required to perform the strength and balance tests. Squat strength requires muscle recruitment for hip and knee joint performance, but these recruitment abilities may not affect static balance performance. However, improved balance scores have been reported after improved hip (Judge et al., 1993) and knee (Kalapotharikos et al., 2004; Vanderhoek et al., 2000) strength. In contrast, increased knee extension strength (Ringsberg et al., 1999) and hip, knee, and ankle training with OKC and CKC exercises (Verfaillie et al., 1997) were not related to improved static and dynamic balance. Pintsaar et al. (1996), and Mattacola and Lloyd (1997) determined that improved ankle strength was related to changes in static balance scores. These inconsistent results may not provide meaningful data with measurement of balance during weight bearing tasks and strength scores assessed with non-weight bearing tests. Future research may find that ankle strength or muscular endurance is related to the ability to balance on the stork stand and wobble board after measurement of ankle strength and muscular endurance in a weight bearing stance. In addition, with research that shows a significant relationship between strength and the incidence of falls in the elderly (Lord et al., 1991), it is possible that higher levels of strength are required to prevent a fall than the strength needed to perform on static assessments of balance. Future studies may also determine mixed results with measurement of weight bearing strength at specific positions in the squat. It is possible that a relationship exists between isometric, weight bearing strength and balance when both tests are completed in the same hip, knee, and ankle position. In addition, a relationship between unilateral strength and dynamic balance may exist.

Balance was not significantly different between the subjects' dominant and non-dominant

leg. Few studies have analyzed the difference in balance performance between contralateral legs. Ross et al. (2004) reported significantly less anterior-posterior sway in the dominant leg and greater knee flexion range of motion from initial foot contact to peak vertical ground reaction force during landings from a height of .36 meters in young adults. These results lend evidence that the dominant leg has better balance and proprioceptive function to control landing forces; however no differences between contralateral limbs were demonstrated in medial-lateral sway and time to stabilize posture after landing (Ross et al., 2004). Colby et al. (1999) also found similar stabilizing times between contralateral limbs after unilateral jump landings. Hoffman et al. (1998) analyzed static postural sway and found no difference in performance between dominant and non-dominant leg. Although balance performance was not different between the dominant and non-dominant leg, the men's (22.3 ± 16.3 %) and women's (24.9 ± 16.0 %) mean side-to-side differences on the stork stand were noteworthy. The men's (4.5 ± 4.9 %) and women's (2.5 ± 3.1 %) mean side-to-side differences on the wobble board were considerably lower. The higher mean side-to-side difference on the stork stand could be the result of less margin for error due to a smaller base of support. Contralateral deficits greater than 10 % have been suggested to increase the risk for lower extremity injury (Elliot, 1978). The mean side-to-side differences warrants the need for further research and pretesting for balance performance prior to participation in sport activities and high intensity activities of daily living. Similar research is needed to compare contralateral leg balance in populations who participate in work or sport activities requiring repetitive asymmetrical tasks.

CONCLUSION

Based on the results in this study, unilateral 1RM squat strength of the dominant and non-dominant leg appears to be unrelated to measures of static balance in healthy young adults. To further investigate the relationship between functional strength and balance, assessment and training should take place under weight bearing conditions. The data indicate that better balance does not necessarily occur on the preferred leg, but side-to-side differences may exist between contralateral legs in young adult men and women. The considerable side-to-side differences found on the stork stand in the men and women support assessment and training to correct differences in balance performance prior to activity to reduce the risk of injury during participation in high intensity activities. Further research is needed

to determine if similar results are found in other populations.

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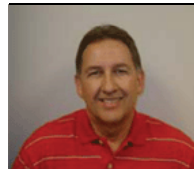Assoc. Prof. in the Department of Kinesiology and Physical Education at Valdosta State University in Valdosta, GA.
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KEY POINTS

- 1RM unilateral squat strength is unrelated to measures of unilateral static balance in young adult men and women
- Static balance is similar between the dominant and non-dominant leg in young adult men and women
- Side-to-side differences in balance warrant assessment and training to correct imbalances prior to participation in activities that present a high risk for injury.

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