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ORIGINAL RESEARCH REPORT

The Relationship Between Hip Strength and the Y Balance Test

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Context: The Y Balance Test was developed as a test of dynamic postural control and has been shown to be predictive of lower-extremity injury. However, the relationship between hip strength and performance on the Y Balance Test has not been fully elucidated. ***Objective:*** The goal of this study was to identify the relationship between components of isometric hip strength and the Y Balance Test, to provide clinicians better guidance as to specific areas of muscle performance to address in the event of poor performance on the Y Balance Test. ***Design:*** Laboratory study. ***Setting:*** Biomechanics laboratory. ***Participants:*** A total of 73 healthy participants (40 males and 33 females) volunteered for this study. ***Intervention:*** None. ***Main Outcome Measures:*** Participants completed the Y Balance Test on the right leg. The authors then measured peak isometric torque in hip external rotation, abduction, and extension. Correlations were calculated between torque measurements, normalized for mass and Y Balance Test performance. Significant relationships were used in linear regression models to determine which variables were predictive of the Y Balance Test performance. ***Results:*** The authors found significant positive correlations between Y Balance Test performance and hip abduction strength. They also found correlations between the Y Balance Test and hip extension and external rotation strengths. Linear regression analysis showed hip abduction to be the only significant predictor of Y Balance performance. ***Conclusions:*** The authors found the strongest association between the Y Balance Test and hip abduction strength. They also showed smaller but significant associations with hip extension and external rotation strength. When entered into a linear regression analysis, hip abduction strength was the only significant predictor of Y Balance performance. Using this information, practitioners should look to hip abduction strength when patients exhibit deficits in the Y Balance Test.

Keywords: injury prevention, postural stability, neuromuscular control

Injuries are an all too common consequence of participation in athletic activities. In the United States, high school athletes alone sustain over 1.4 million injuries each year, with over half of those injuries isolated to the lower-extremity.[1] Significant efforts have been dedicated to develop methods that identify individuals who may be at greatest risk for lower-extremity injury. One such method, the Y Balance Test, was developed by simplifying the Star Excursion Balance Test (SEBT) by reducing it to 3 directions (anterior, posterolateral, and posteromedial), and providing standardized equipment to make the test easier to administer.[2] An additional advantage of the Y Balance Test is that in addition to a score for each direction, a "composite score" can be calculated that is an average of the 3 reach directions. This composite score reflects the patient's ability to perform a wide variety of motions and distills this into a single score.

Numerous studies have shown that both the SEBT and the Y Balance Test are associated with lower-extremity injury in various patient populations. Plisky et al[3] showed an increased risk of lower-extremity injury in high school basketball players with an anterior reach asymmetry on the Y Balance Test of 4 cm or greater, or with a normalized composite score less than 94.0%. Similarly, Butler et al[4] did not identify any noncontact lower-extremity injuries during a season of college football when players had a Y Balance Test composite score greater than 89%, and Smith et al[5] found an increased risk of noncontact injury in college athletes with an anterior reach asymmetry of 4 cm or greater. Interestingly, when Herrington et al[6] compared patients with anterior cruciate ligament (ACL) injuries and normal controls, they found significant differences between the healthy controls and both the ACL deficient knee and the uninjured knee on several directions of the SEBT. Based on this, they concluded that there could be an underlying risk factor for ACL tear that can be identified based on poor performance on postural stability tests. These studies highlight the link between the SEBT and Y Balance and injury risk; however, to effect change, clinicians need to be able to pinpoint which modifiable factors cause poor performance on this test, such as strength, endurance, and neuromuscular control, in order to intervene and potentially reduce injury risk.

The Y Balance Test requires the subject to be able to control his or her body while maintaining a single-leg stance. Potentially, this requires adequate hip girdle strength to maintain stability of the pelvis and trunk throughout the test. Although relationships have been reported between various components of lower-extremity and core strength and injury,[7–9] the relationship between hip strength and performance on the Y Balance Test has yet to be fully elucidated.[10–12] Only 2 studies to date have assessed correlations between the SEBT or Y Balance Test and hip strength. Hubbard et al,[11] in a study of participants with chronic ankle instability, showed positive correlations between both hip abduction strength and hip extension strength and posteromedial and posterolateral reach distance on the SEBT. Conversely, Lee et al,[13] in a study of elderly females, did not find significant correlations between hip abduction strength and the anterior or posterolateral reaches of the Y Balance Test. They did, however, show strong correlations between hip abduction strength and the posteromedial reach, as well as hip extension strength and all 3 directions of the Y Balance

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Test. Several studies have reported that different individual muscles are utilized in the tested reach directions,[11–14] although no study to date has examined the relationship between hip strength and Y Balance composite score across a healthy population of males and females. This research is important because, theoretically, any muscle strength correlated with poorer Y Balance performance could be addressed by targeted strengthening to improve Y Balance Test performance and reduce injury risk. Therefore, it is important to examine which muscle strength components contribute to better performance in the Y Balance Test.

The goal of this study was to identify the relationship between specific components of hip strength with performance on the Y Balance Test, including the composite score. We hypothesized that hip abduction, extension, and external rotation would predict performance on the Y Balance Test performance. These hip strength components were selected as they have each been implicated in either Y Balance Test performance[11,13] or injury risk[7,9] and are easily testable in a clinical setting using previously published protocols utilizing a handheld dynamometer.[7,15]

Methods

Our academic medical center's institutional review board approved this study. All participants provided their written informed consent before participating.

Subjects

A total of 73 participants were recruited for this study from a population of convenience via advertisements posted on our university medical center campus. See Table 1 for descriptive data. All participants were healthy and met the following inclusion criteria: (1) age between 18 and 45 years; (2) currently free of any trunk, hip, or knee injuries within the last 3 months; and (3) no previous history of injury or surgery that may affect their trunk, hip, or knee function. All participants completed a Tegner Activity Scale,[16] which scale ranges from 0 (on sick leave or disability due to knee pain) to 10 (participation in national- or elite-level competitive sports) and is indicative of their current level of physical activity. The participants reported a mean Tegner score of 5.88 (1.07), indicating current involvement in moderate recreational physical activity. Participants also indicated their "dominant leg" by answering which leg they would use to kick a ball.

Y Balance Testing

Participants completed the Y Balance Test (Move2Perform, Evansville, IN) in a manner previously described in the literature.[2,17–22] The participants stood with 1 leg, the stance leg, on the starting block, and used their opposite leg, the reach leg, to push the reach indicator box as far as possible in the anterior, posterolateral, and posteromedial directions. Attempts did not count if the participant was unable to maintain a single-leg stance throughout the entire movement, rested the left foot on top of the indicator box while reaching, kicked the indicator box forward in an attempt to gain extra distance, or did not return to center with maintained balance. Each participant completed 3 testing trials in each direction with each leg after completing 6 practice trials, which were included to familiarize the participant with the testing maneuvers.[20] Participants were allowed to take a short rest between repetitions if needed to prevent fatigue. Only the values from the 3 testing trials were used to calculate the subject's scores. Scores for each direction (anterior, posteromedial, and posterolateral) were calculated by dividing the average reach distance (in cm) by the participant's leg length (in cm) and multiplying by 100 to get the percentage of the leg length. The patient's leg length was measured from the most prominent aspect of the anterior–superior iliac spine to the distal tip of the ipsilateral medial malleolus. To calculate the composite score, the sum of maximum reaches in each of the 3 directions was divided by 3 times the leg length.[3]

Table 1 Summary Characteristics and Demographic Data of Study Population

	Mean	SD
Age, y (n = 73)	25.40	5.20
Males/females	40 (55%)/33 (45%)	–
Height, cm	175.29	10.40
Mass, kg	73.22	14.89
Tegner score	5.88	1.07

Strength Testing

Peak isometric hip external rotation, hip abduction, and hip extension strength were measured using previously reported protocols.[9,23–26] Each direction was tested a total of 4 times using a handheld dynamometer (Nicholas MMT; Lafayette Instrument, Lafayette, IN) secured in place with stabilization straps.

Hip abduction strength was tested by having the patient lie in a side-lying position with the left side down and the knee extended. The handheld dynamometer was secured to the patient with the use of a stabilization strap wrapped around the table. The dynamometer was placed 5 cm proximal to the lateral joint line of the knee. The patient abducted the right leg toward the ceiling with maximal force for 5 seconds.

Hip extension was tested in the prone position. The participant laid in the prone position with the right knee flexed to 90°. The dynamometer was secured 10 cm proximal to the popliteal fossa using a stabilization strap secured around the table. The participant then extended the hip as if trying to touch the ceiling with the plantar surface of the foot, maintaining maximal effort for a total of 5 seconds.

Hip external rotation was tested with the participant in a seated position and the knee flexed to 90°. The handheld dynamometer was again secured to the participant's leg using stabilization straps that were wrapped around a stable post on the right side of the patient. The landmark used for placement of the dynamometer was a point on the medial aspect of the participant's lower leg, 5 cm proximal to the distal tip of the medial malleolus. To perform the test, patients externally rotated their leg at the hip as if trying to look at the bottom of their shoe for 5 seconds.

Verbal encouragement was provided throughout all trials to ensure maximal effort. The participants repeated these tests for 4 trials in each direction. The first trial was a practice trial, and the final 3 were used for experimental data. Finally, we calculated the average torque over the 3 trials and normalized for length and mass using previously published protocols.[15,27] For hip extension and hip abduction torque, the following formula was used: torque = [(isometric force in N) × (femur length in m)]/(mass in kg). Hip external rotation strength was calculated as follows: torque = [(isometric force in N) × (tibia length in m)]/(mass in kg).

Data Analysis

All statistical analyses were performed using SPSS 23 Statistics Software (SPSS Inc, Chicago, IL). Data were tested for normality using the Shapiro–Wilk test. Averages and SDs were calculated for each of the variables, on each leg. *t* tests were performed to determine if there were any between-limb differences of the dominant and nondominant legs. Pearson correlation coefficients were calculated between the 3 hip strength measurements and the Y Balance Test scores. To describe the strength of the correlation, the following scale was used for the absolute value of the correlation coefficient (r): strong relationship ($.50 \le r \le 1.0$), moderate relationship ($.3 \le r < .5$), and weak relationship ($r < .3$).[28] The level of significance for all analyses was set at $P \le .05$. Hip strength variables with significant correlations were then used in stepwise multivariate linear regression models to determine which variables were predictive of the Y Balance Test scores.

Results

This study included 73 healthy participants with a mean age of 25.40 (5.20) years (Table 1). Leg dominance was available for 49 of the 73 participants. Dominant leg and nondominant leg testing results showed no significant difference between legs for all variables (Table 2). As there were no differences when we compared results from the "dominant leg" and the "nondominant leg," all subsequent statistical analysis using the trials only on the right leg were used for further analysis. All participants completed Y Balance and isometric hip strength testing on the right leg (Table 3). Hip abduction, hip external rotation, and hip extension all showed significant positive correlations of varying strength with each of the 4 Y Balance Test scores (Table 4). The only relationship that did not reach statistical significance for the right leg was posteromedial reach and hip external rotation, which approached significance with a *P* value of .05. All significant hip strength variables were then entered into stepwise linear regression analyses. Linear regression analyses showed hip abduction strength to be the only significant predictor of Y Balance Test performance (Table 5). Isometric hip abduction strength was found to be significantly predictive of all directional scores as well as the composite score.

Table 2 Dominant Leg Versus Nondominant Leg Testing Results

Subjects			
Gender	Male: 26/49 (53.1%)	Female: 23/49 (46.9%)	
Leg dominance	Right: 43/49 (87.8%)	Left: 6/49 (12.2%)	
Test	**Dominant leg**	**Nondominant leg**	***P* value**
Y Balance Test (%leg length)			
Anterior	72.12 (7.56)	71.94 (6.78)	.90
Posterolateral	112.05 (11.05)	112.18 (11.06)	.95
Posteromedial	110.85 (12.73)	110.55 (11.84)	.91
Composite	98.34 (9.36)	98.22 (8.80)	.95
Isometric hip strength, N·m/kg			
Abduction	20.28 (5.19)	19.11 (5.06)	.26
External rotation	6.72 (2.04)	6.48 (2.01)	.56
Hip extension	14.58 (4.99)	14.13 (2.98)	.51

Table 3 Right Leg Y Balance and Isometric Hip Strength Testing Results

Test	Mean (SD)
Y Balance Test (%leg length)	
Anterior	70.75 (8.08)
Posterolateral	111.70 (11.33)
Posteromedial	109.63 (12.44)
Composite	97.36 (9.50)
Isometric hip strength, N·m/kg	
Abduction	19.63 (4.76)
External rotation	7.09 (2.09)
Hip extension	14.26 (4.90)

Table 4 Correlations Between Y Balance and Isometric Hip Strength

	r	*P* value[a]	Strength of correlation[b]
Anterior			
Hip abduction*	.377	.001	Moderate
Hip external rotation*	.277	.02	Weak
Hip extension*	.369	.001	Moderate
Posterolateral			
Hip abduction*	.335	.004	Moderate
Hip external rotation*	.253	.03	Weak
Hip extension*	.300	.01	Moderate
Posteromedial			
Hip abduction*	.385	.001	Moderate
Hip external rotation	.229	.05	Weak
Hip extension*	.333	.004	Moderate
Composite			
Hip abduction*	.409	<.001	Moderate
Hip external rotation*	.281	.02	Weak
Hip extension*	.371	.001	Moderate

[a]Level of significance set at $P \le .05$. [b]Scale: strong = $.50 \le r \le 1.0$, moderate = $.3 \le r \le .5$, and weak = $r < .3$.
*Significant correlation.

Table 5 Linear Regression Analysis Results

	Adjusted r^2	*P* value
Anterior		
Hip abduction	.130	.001
Posterolateral		
Hip abduction	.100	.004
Posteromedial		
Hip abduction	.136	.001
Composite		
Hip abduction	.155	<.001

Note: Hip external rotation and extension were not found to be predictive of any directional scores or the composite score.

Discussion

The purpose of this study was to identify the relationship between hip strength and Y Balance Test performance. The strongest correlations were found between the Y Balance Test scores and hip abduction strength. Our study also showed smaller, but statistically significant, correlations between the Y Balance Test composite score and hip extension and hip external rotation strength. In fact, the only relationship without a significant correlation was between hip external rotation and posteromedial reach score, although it did approach significance. Hip abduction strength was found to be the only significant predictor of Y Balance Test performance in regression analysis. These results have a number of clinical implications.

Unlike several other studies about the Y Balance,[3,4,6,11,13] this population was not limited to a specific sport, injury, or gender. Males and females were included in a single analysis for this study. To allow for this, the Y Balance scores were normalized for leg length. Previous studies have shown no difference in SEBT or Y Balance Test scores between genders when normalized in such a manner.[29,30] Analysis of the 49 subjects for which leg dominance information was available also showed no significant difference between Y Balance scores or isometric hip strength between dominant and nondominant legs. This is likely due to our participants being physically active, not injured, and not heavily involved in a single sport that would result in limb prevention asymmetries.

The most important finding of this study was that hip abduction was predictive of Y Balance Test performance in all 3 directions as well as the composite score. Gluteus medius and gluteus minimus, along with assistance from other muscle groups, contribute to hip abduction.[12,31,32] Hip abduction strength in the stance leg in a single-leg stance serves to stabilize the pelvis by resisting the force of gravity on the unsupported reaching leg and hemipelvis. Importantly for athletes, hip abduction strength helps prevent the hip from falling into adduction during single-leg activities, which could place an excessive valgus force on the knee.[33] In fact, hip abduction weakness has recently been demonstrated to be predictive of noncontact ACL injury.[9] We hypothesized that hip abduction strength would be important to performance in the Y Balance Test, as the test requires the performance of a series of single-leg squat-like maneuvers. In addition, the posteromedial and posterolateral reaches require the subject to abduct or adduct the opposite leg away from midline, which could also require hip abduction strength for reach and stability. Lee et al, in a study of 40 women aged 40–80 years old, found correlations of .682, .719, and .653 between hip abduction and anterior, posteromedial, and posterolateral reach distances, respectively.[13] Similarly, Hubbard et al,[11] in a study of 30 patients with chronic ankle instability, found correlations of .51 and .49 between hip abduction strength and posteromedial and posterolateral reach, respectively. Although we found weaker correlations than the 2 previous studies, our patient population was very different. This study is composed of younger, healthy, physically active patients who likely are better able to use hip and trunk muscles than an injured population. Our study also extends these previous findings, as this study also analyzed the Y Balance Test composite score, which incorporates all of these directions into a single score. Importantly, previous studies have suggested that performance on the composite score may be a better indicator of an athlete's risk of injury than any single direction by itself.[3,4] Furthermore, we have extended prior studies by finding that hip abduction strength is predictive of Y Balance Test performance in all directions. This is likely due to hip abduction's potential role in stabilizing the pelvis during a single-leg stance, which is required in all 3 directions. The small r^2 values found on linear regression analysis show that only 10% to 15% of Y Balance performance could be attributed to hip abduction strength. These results suggest that improving a patient's isometric hip abduction strength could also mildly improve the patient's Y Balance performance and potentially decrease the risk of injury. However, other factors, such as trunk, core, knee, and ankle strength, play an important role in frontal plane stability while performing the Y Balance Test.

In addition to our findings regarding hip abduction strength, our study also showed an association between hip extension strength and Y Balance performance. However, regression analysis did not show hip extension strength to be predictive of a participant's performance on the test. Gluteus maximus, in addition to the posterior head of adductor magnus and the muscles of the posterior compartment of the thigh, acts to extend the hip.[32,34–36] These muscle groups also serve to resist the force of gravity on the trunk when it is positioned anterior to the axis of rotation of the hip joint, as well as to return the flexed hip to the midline in the sagittal plane.[32,37] We hypothesized that the performance of the hip extensors would be useful in the Y Balance Test, as some participants choose to spend significant time with the trunk flexed anteriorly over the planted foot during the test. In their previous study, Lee et al[13] found strong correlations ($r > .7$) between hip extension strength and all 3 directions of the Y Balance Test. Likewise, Hubbard et al[11] showed correlations of .48 and .49 between hip extension strength and posteromedial and posterolateral reach, respectively. In our study, similar to the previous studies, there were positive associations between the Y Balance Test and hip extension strength. However, hip extension strength was not predictive of any of the scores, including the composite score. This implies that focused training to improve the Y Balance composite score should focus less on hip extension strength than on other areas.

Similar to our findings for hip extension strength, our study demonstrated weak but statistically significant correlations between hip external rotation strength and Y Balance Test scores. Despite this significant relationship, our regression analysis did not show that external rotation strength is predictive of Y Balance Test performance. Several muscles aid in external rotation of the hip joint, including the gluteus maximus and the short external rotators.[32,36] The external rotators function during activities that require rotation of the body and pelvis about a planted leg, such as in athletic cutting maneuvers.[32] We hypothesized that subjects would also utilize this motion in the Y Balance Test, as many subjects choose to rotate the trunk over the planted leg to gain more distance, especially in the posteromedial and posterolateral directions. We are aware of no studies to date that directly studied the association between hip external rotation strength and performance on the Y Balance Test or the SEBT. However, several studies have linked hip external rotation strength to injury risk.[7,9] In a prospective study of 139 athletes, Leetun et al[7] found that subjects who sustained an injury over the course of the study were weaker in hip external rotation strength than their peers who remained uninjured. When they performed logistic regression analysis, they found hip external rotation strength to be the only variable tested to be predictive of injury. Our findings suggest that hip external rotation weakness, like hip extension weakness, is less likely related to poor performance on the Y Balance Test. Furthermore, Y Balance performance should not be used as a larger screening tool to identify individuals with hip external rotation weakness.

These findings have important clinical implications. By demonstrating that isometric hip abduction strength is a predictor of performance on the Y Balance Test, we would expect that focused isometric hip abduction strengthening programs should concurrently improve both hip strength and the Y Balance Test performance and potentially reduce future injury risk. In addition, this study has provided insight into which muscle functions are contributing to the performance on the Y Balance Test. As the Y Balance Test and hip strength testing have both been shown to be associated with lower-extremity injury,[3,5,7,9] it is possible that at least a portion of the Y Balance's injury risk predictive ability is due to its detection of hip strength deficiencies. As the correlations were only weak to moderate for all 3 strengths tested, there is likely one or several other parameters associated with performance on the Y Balance Test that have yet to be identified.

There are important limitations in this study. First, we only tested healthy individuals with a mean age of 25.4 years. Although Lee et al[13] found stronger correlations between isometric hip strength parameters and Y Balance testing than those reported in this study, the correlations reported by Hubbard et al[11] were more similar. The healthy participants in the study by Lee et al[13] had an average age of 65.73 years, whereas the participants with chronic ankle instability in the study by Hubbard et al[11] had an average age of 20.3 years, also much closer to the average age of 25.40 years of the healthy participants in this study. This suggests that participants' age could play a larger role than their injury status and could explain the discrepancy seen between correlations among the different studies. In addition, on average our participants identified that they currently participate in at least recreational physical activity. This may decrease the generalizability of our study to injured patient populations, or to patients younger than or older than our sample population. However, the use of healthy subjects decreased the chance that performance was affected by lower-extremity pathology such as patellofemoral pain, ankle instability, or other limitations that would prevent maximal performance. Furthermore, the mean age of subjects tested in this study is similar to that of the most physically active age groups described in the literature[38] and is likely representative of the age group likely to benefit most from injury prevention.[39] This study also combined males and females in this analysis. Although previous studies have shown no difference between genders, when Y Balance scores are normalized for leg length,[29,30] a difference in strategy may exist due to different centers of mass or body types. In addition, we tested hip strength in an isometric fashion, which may not be representative of the Y Balance Test, as it is a dynamic test incorporating strength, endurance, balance, flexibility, and neuromuscular control. Generalization of these results should be limited to isometric hip strength parameters. However, isometric hip strength testing with a handheld dynamometer is standard practice in both clinical and research settings, and standardized testing methods have provided for reliable and accurate comparisons across multiple studies, including those by Lee et al[13] and Hubbard et al,[11] which previously assessed relationships between hip strength and the Y Balance Test. Furthermore, components' muscular function are often correlated, and it is possible that isometric hip strength measurements provide a reasonable estimation of other parameters of hip function, such as dynamic strength, endurance, or proprioception.[40] Furthermore, prospective research is needed to determine if increases in isometric hip strength translate to improved Y Balance performance and ultimately to decreased lower-extremity injury risk. Finally, given the modest correlations and r^2 values found in this study, further research is needed to identify other factors associated with Y Balance performance.

Conclusions

In conclusion, this study demonstrated significant weak to moderate positive correlations between Y Balance Test performance and isometric hip abduction, external rotation, and extension strengths. Regression analysis indicated that isometric hip abduction strength was a moderate predictor of the Y Balance scores. Using this information, health care practitioners should consider implementing targeted isometric hip strengthening exercises for individuals with poor Y Balance Test performance. Furthermore, these findings have significant clinical implications when considering the injury prediction capabilities of both the Y Balance Test and isometric hip strength testing. Knowledge of these relationships can assist practitioners in developing injury-screening and prevention programs.

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