Weight-Bearing Versus Traditional Strength Assessments of the Hip Musculature

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Context: Traditional nonweight-bearing (NWB) hip-strength assessments may not directly translate to functional strength during weight-bearing (WB) activity. How NWB assessments of hip muscle strength compare with WB assessments in various positions is currently unknown.

Objective: To determine the magnitude of the differences and correlations between NWB hip strength and WB functional strength during the squatting and lunge (LNG) positions in female athletes.

Design: Crossover design.

Setting: Laboratory.

Patients or Other Participants: Female athletes (N = 51, age = 16.2 ± 3.5 years, height = 161.5 ± 8.3 cm, mass = 58.3 ± 11.6 kg).

Intervention(s): Isometric resistance (N/kg) was determined for the dominant and nondominant limbs via WB assessments (squat-bilateral [legs tested simultaneously], squat-unilateral, and lunge positions) and NWB assessments (hip external rotation [HER], hip extension [HEXT], and hip abduction [HAB]).

Main Outcome Measure(s): To compare differences between positions ($P \le .05$), we used effect sizes (*d*) and matchedpairs *t* tests, and we calculated Pearson *r* and R^2 values.

Results: During the squat-bilateral on the dominant limb, females produced the most hip torque (6.13 ± 1.12 N/kg). The magnitudes of differences were very large compared with HER (3.96 ± 0.83, d = 2.2), HEXT (3.22 ± 0.69, d = 3.2), and HAB (3.80 ± 1.01, d = 2.2; all *P* values \leq .01), and positions were moderately correlated (r = 0.347-0.419, $R^2 = 0.12-0.18$). The lunge position produced the least amount of torque in the dominant limb (2.44 ± 0.48 N/kg) compared with HER (d = -2.3), HEXT (d = -1.3), and HAB (d = -1.7; all *P* values \leq .001), and correlations were small to moderate (r = 0.236-0.310, $R^2 = 0.06-0.10$).

Conclusions: Strength in WB positions was different than strength evaluated using traditional NWB assessments in female athletes. Weight-bearing tests may provide clinicians with additional information regarding strength and function.

Key Words: functional strength evaluation, weight bearing, hip dynamometry

Key Points

- Hip strength measured with handheld dynamometry differed in the weight-bearing and non-weight-bearing positions.
- Weight-bearing hip-strength assessments showed internal consistency and may serve as adjuncts to current clinical strength evaluations.
- Among female athletes, hip strength was greatest when tested bilaterally in a squat position and least during a lunge.

unctional strength, or the development of adequate muscle force during dynamic motion, is important in athletic movements such as landing from a jump, cutting, and changing directions. Weakened hip muscles, specifically the hip abductors and external rotators, are associated with abnormal lower extremity biomechanics and are believed to be contributing factors in multiple lower extremity injuries.^{1,2} The gluteus medius and gluteus maximus help to maintain proper hip and knee dynamic stability by eccentrically limiting excessive hip adduction and internal rotation.^{1,3} Thus, the inability of the hip abductors and external rotators to provide dynamic stability may result in dynamic valgus of the knee,¹ which may increase the risk of knee injury.⁴ This is especially true for females, who may depend more on the hip muscles to control the lower extremity during functional tasks.⁵

Therefore, the clinician's ability to functionally assess the strength of the hip muscles is essential for injury prevention and rehabilitation.

The most clinically viable option for assessing strength is manual muscle testing and handheld dynamometry. Compared with isokinetic dynamometers, handheld dynamometry is significantly lower in cost and easier to apply. However, historically, it has been used to evaluate muscular strength in non–weight-bearing (NWB) positions. Given the differences in muscle activation demonstrated between NWB and weight-bearing (WB) activities,^{6,7} there may be a disconnect between using NWB strength assessments for determining the injury risk during functional WB activities. Conducting WB strength testing in place of the traditional NWB methods may enable us to better understand the links among clinical strength assessments, functional strength, and injury risk.

Lee and Powers⁸ proposed a WB assessment of hip strength. They demonstrated that strength tests of dominant-limb hip abduction (HAB) and hip external rotation (HER) performed while the participant was in a standing squat were more reliable than those in an NWB side-lying position for HAB and were moderately correlated with the NWB assessment.⁸ Because the only positions tested were the dominant-limb WB squat and NWB HAB, how the NWB assessment of the strength of other hip muscles (HER, hip extension [HEXT], and HAB) compares with WB strength assessments in various positions is unknown. Hip-muscle activation patterns change when the task, joint angles, and type of WB activity are varied,⁷ so testing in multiple WB positions could be advantageous for clinicians. Additionally, when testing strength in NWB positions, clinicians do not need to consider the opposite (untested) limb in the same fashion as during a WB test. The effects of strength testing the limbs bilaterally and simultaneously versus unilaterally and separately during WB testing remain unknown.

Therefore, the purpose of our study was to compare the differences and correlations among 3 traditional NWB and 3 WB strength assessments in the dominant and nondominant limbs of healthy active female athletes. We studied the NWB positions of HER, HEXT, and HAB and compared those with 3 WB positions of a squat tested bilaterally (squat-bilateral [SQ-B]) and unilaterally (squatunilateral [SQ-U]) as well as a lunge (LNG). We hypothesized that large differences and moderate correlations would be present between the NWB and WB positions for both the dominant and nondominant limbs. Because the SQ-B allows both lower extremities to be tested simultaneously, we proposed that this position would yield the greatest strength versus each NWB test, in which the individual muscles are selectively isolated against gravity. Additionally, we hypothesized that the LNG would be the weakest of all the WB and NWB assessments because resisting externally applied forces while in a greater hip and knee-flexed position is more difficult for the posterolateral hip muscles.

METHODS

To better understand how strength testing may differ between test positions, we evaluated 2 series of dominantand nondominant-limb strength tests in a group of female athletes. The results of traditional NWB strength assessments performed on a table were compared with those of the newly proposed WB tests. These assessments were chosen based on previous research and potential application for clinicians.

Participants

Fifty-one female athletes (age = 16.2 ± 3.5 years, range = 12-25 years, height = 161.5 ± 8.3 cm, mass = 58.3 ± 11.6 kg) who participated in basketball (n = 14), soccer (n = 36), and volleyball (n = 1) were recruited from local universities (n = 18), high schools (n = 27), and intermediate schools (n = 6). Participants completed the Physical Activity Readiness Questionnaire so that we could screen for recent inactivity or serious medical conditions.

Inclusion criteria were no history of knee surgery or lower extremity injury in the past 6 months that caused a reduction in physical activity. All study procedures were approved by the University Human Studies Program. Before study enrollment, participants and legal guardians provided informed consent and assent in accordance with the University Human Studies Program.

Procedures

Participants reported to the University Human Performance Lab for a single session of data collection. Anthropometric data were obtained using a wall-mounted stadiometer (Seca telescopic stadiometer; Country Technology Inc, Gays Mills, WI) for height and a calibrated scale (Detecto Inc, Webb City, MO) for body mass. Limb dominance was determined according to which foot each person would prefer to use to kick a ball. Each participant performed a 5-minute, self-selected warm-up on a stationary bicycle. Strength was quantified by a single examiner (A.U.) using 2 microFET 2 handheld dynamometers (HHDs; Hoggan Scientific, LLC, Salt Lake City, UT) to determine force (N). Participants were instructed to hold the demonstrated starting position and use their muscle to resist a break-test force. Break tests have been shown to be reliable and appropriate for strength assessments.⁹ No participant was able to overcome the force, and therefore, each individual trial was actually a break test.

Both HHDs produced valid measures within 1 lb (0.45 kg) when tested with a 50-lb (22.68-kg) weight. Intrarater reliability of the examiner was established using the 2,1 method of Weir¹⁰ to determine the intraclass correlation coefficient (ICC; a 2-way random model that accounted for systematic errors), and the precision of the strength assessments was examined via the standard error of measurement (SEM) from a pilot study (n = 10). The ICCs for WB measures from pilot testing were SQ-B = 0.71, SQ-U = 0.87, and LNG = 0.84, with SEMs of SQ-B = 0.42N/kg, SQ-U = 0.19 N/kg, and LNG = 0.22 N/kg. The ICCs for the NWB measures were HER = 0.91, HEXT = 0.73, and HAB = 0.87, with SEMs of HER = 0.29 N/kg, HEXT = 0.44 N/kg, and HAB = 0.34 N/kg. The total average error (ratio of SEMs: average peak strength) was small across positions and 8.3% of total peak strength. The minimally important clinical differences were calculated (MD = SEM \times 1.96 $\times \sqrt{2}$), and changes of 1.16 N/kg (SO-B), 0.52 N/kg (SQ-U), and 0.61 N/kg (LNG) were considered meaningful and real.

The WB Assessments. The WB assessments (Figure A– C) were conducted in standing-squat and LNG positions with a valgus force applied just proximal to the test knee joint. Functional strength was evaluated during the SQ-B (dominant and nondominant limbs simultaneously) and SQ-U (each dominant and nondominant limb in separate trials), as well as unilaterally during the LNG (dominant and nondominant limbs separately). Participants stood in 30° of hip flexion and 50° of knee flexion with neutral lumbar lordosis, feet parallel and shoulder-width apart, and arms folded across their chest for both standing-squat positions. In the squat position, these angles reportedly produced the greatest force of the abductor and external rotators; squatting was moderately correlated with strength during side-lying HAB (r = 0.75, P < .01) and had excellent test-



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Figure. Test positions for A, squat-bilateral (both limbs tested simultaneously), B, squat-unilateral (right and left tested separately), and C, lunge (right and left tested separately). The non-weight-bearing test positions were D, hip abduction, E, hip external rotation, and F, hip extension.

retest reliability (ICC = 0.99).⁸ For the LNG position, participants stood with their feet shoulder-width apart and a stride length of 60% of their height, with 60° of knee flexion.¹¹ The rear (nontest) leg was externally rotated to provide stability and prevent the heel from rising. Participants were instructed to maintain this position with their arms folded across their chest during testing. Because this was a novel position, test-retest reliability was evaluated during pilot testing.

The NWB Assessments. The NWB assessments (Figure D-F) were conducted in the following order: HER, HEXT, and HAB. The HHD was positioned just proximal to the

knee joint of the test leg for all NWB assessments. The starting position for HER was side lying with 45° of hip flexion and 90° of knee flexion, which is often called the clamshell position. The feet were positioned together and aligned parallel with the long axis of the torso. Participants were instructed to raise the test knee in 30° of HAB while keeping the feet together. The starting position for HEXT was standing prone at 60° of hip flexion.^{12–14} Participants were instructed to extend the test leg until it was parallel to the long axis of the torso, and then they were positioned in 30° of abduction, 20° of external rotation, and 90° of knee flexion, which is often called a *donkey-kick position*. The

nontest leg was in contact with the floor and the knee slightly bent for stability. The starting position for HAB was side lying with the nontest leg in 30° of hip and knee flexion and the test leg parallel with the long axis of the torso.¹⁵ Participants were instructed to raise the test leg in 10° of abduction.

The WB assessments were performed first, starting with the SQ-B, SQ-U, and LNG, and followed by the traditional NWB assessments (right leg tested first in each position). Each participant performed submaximal trials before the assessment to ensure correct positioning and familiarization. Because this was part of a larger study, randomization of testing procedures was not feasible; therefore, a minimum of 90 seconds of rest was provided between trials to eliminate the effects of fatigue on strength measures. Use of adjacent muscles during the NWB assessments, as observed by deviation from the intended motion and plane, was monitored and corrected if observed (eg, increasing hip flexion or HER or both during the sidelving HAB test). Oral encouragement and feedback were given to facilitate a maximal effort. Participants completed 3 maximal efforts separated by 90 seconds of rest. The greatest force production of the 3 trials was scaled by body mass (N/kg) and used for analysis.

Statistical Analyses

We calculated means and standard deviations for key variables. The Levene test was used to test for homogeneity of variance, and normal distribution was verified using the Shapiro-Wilk test. Results of the WB and NWB assessments were considered separately for each leg (ie, SQ-B) dominant limb was compared with the HER dominant limb). Two-tailed, matched-pairs t tests were conducted to evaluate the differences between WB functional strength and NWB hip strength (N/kg), with the effect size (d)calculated to determine the magnitude of difference between positions (small = 0.2, medium = 0.5, large = 0.8, very large = 1.3).¹⁶ The 3 NWB strength assessments were also calculated as percentages of their WB counterparts (NWB/WB). We computed Pearson product moment correlation coefficients and subsequent R^2 values (small = 0.02, medium = 0.15, large = 0.35) to determine the variance explained between each WB and NWB assessment for the dominant and nondominant limbs separately.^{16,17} All statistical analyses were performed using SPSS (version 26.0; IBM Corp, Armonk, NY), with statistical significance established at $\alpha < .05$. An a priori power analysis revealed that a sample of n = 42 was required for 2-tailed matchedpairs t tests to achieve $\beta = 0.95$, $\alpha = .05$, and an effect size of 0.8.

RESULTS

Means, standard deviations, effect-size differences, and t test results for the comparisons between WB and NWB strength assessments are reported in Table 1. Participants produced the greatest amount of force during the SQ-B; effect-size differences were very large compared with each NWB assessment. In the dominant limb, as a percentage of the SQ-B, HER was 65%, HAB was 62%, and HEXT was 53%. In the nondominant limb, as a percentage of the SQ-B, HER was 74%, HAB was 69%, and HEXT was 61%.

The SQ-U displayed similar patterns of strength differences, but the effect sizes were more varied. Effect sizes were small for the dominant limb and medium for the nondominant limb compared with HER. Medium-sized effects were present when the SQ-U was compared with HAB and very large compared with HEXT for both limbs. When calculated as a percentage of the SQ-U in the dominant limb, HER was 95%, HAB was 91%, and HEXT was 75%. As a percentage of the SQ-U in the nondominant limb, HER was 91%, HAB was 84%, and HEXT was 75%.

Conversely, the participants produced the least amount of force during the LNG. We found very large effect-size differences when the LNG was compared with each of the NWB tests. When calculated as a percentage of the LNG in the dominant limbs, HER was 162%, HAB was 156%, and HEXT was 132%. When calculated as a percentage of the LNG in the nondominant limb, HER was 169%, HAB was 156%, and HEXT was 138%.

Correlations and R^2 values can be seen in Table 2. We observed a general trend in which the nondominant-limb NWB results were more related to the WB results than to their dominant-limb counterparts. Across all values, the SQ-U shared the most variance with the NWB tests, with an R^2 range of 18% to 31%. The SQ-B followed with an R^2 range of 10% to 26%. The LNG results were the least similar to those of the NWB tests with an R^2 range of 3% to 28%.

DISCUSSION

Our main finding was that in female athletes, strength tested in WB positions was different than strength evaluated using traditional NWB hip-strength assessments. Participants produced the greatest strength in the SQ-B and the least strength in the LNG position. The SQ-B and LNG results differed most from all 3 traditional hip-strength measurements due to values that were greater than the minimally important clinical differences and their very large effect sizes. Previous researchers⁸ have advocated for the use of WB strength assessments as clinical tools, and we have added information for comparing strength differences with respect to WB status. We also provided an analysis of multiple hip-strength assessments and WB positions for the dominant and nondominant limbs. Results for the dominant and nondominant limbs demonstrated internal consistency: the greatest strength occurred during the SQ-B, followed by the SQ-U. The NWB assessments were the third highest, and within the NWB subcategory, they were ranked as HER (clamshell position), HAB (side lying), and then HEXT (donkey kick).

The significance of these WB assessments for clinicians is still not entirely clear, but they may serve as an important first step in developing additional clinical tools for evaluation, treatment, and injury risk reduction. We chose to test multiple WB positions so that the increasing amount of hip flexion from the squat to LNG positions would challenge the hip musculature in various ways. For example, the gluteus medius⁶ and maximus¹⁸ are subject to increased demands and activation depending on the functional task and hip angles, so it seems logical that a variety of WB test positions should be examined. Furthermore, we showed that the dominant and nondominant limbs of female athletes produced more force when

Table 1. Weight-Bearing (WB) and Traditional Non–Weight-Bearing (NWB) Strength Assessments (N/kg; N = 51)

Dominant Leg						Nondominant Leg						
95% Cl of Mean WB NWB Mean ± SD Difference <i>t</i> Value <i>d</i> Value					WB	t Value	e d Value					
Squat-bilateral ^a		6.13 ± 1.12				Squat-bilateral ^a		5.26 ± 0.93				
	HER	3.96 ± 0.83	1.87, 2.47	14.40	2.2	•	HER	3.92 ± 0.76	1.10, 1.58	11.28	1.6	
	HEXT	3.22 ± 0.69	2.60, 3.21	19.05	3.2		HEXT	3.21 ± 0.66	1.79, 2.31	15.83	2.5	
	HAB	3.80 ± 1.01	2.00, 2.66	14.26	2.2		HAB	3.62 ± 0.89	1.34, 1.94	10.93	1.8	
Squat-unilateral ^a		4.18 ± 0.63				Squat-unilateral ^a		4.30 ± 0.71				
	HER⁵	3.96 ± 0.83	0.02, 0.42	2.16	0.3		HER	3.92 ± 0.76	0.19, 0.58	3.94	0.5	
	HEXT	3.22 ± 0.69	0.76, 1.16	9.60	1.4		HEXT	3.21 ± 0.66	0.90, 1.29	11.11	1.6	
	HAB	3.80 ± 1.01	0.13, 0.63	3.00	0.5		HAB	3.62 ± 0.89	0.46, 0.91	6.14	0.8	
Lungeª		2.44 ± 0.48				Lungeª		2.32 ± 0.42				
	HER	3.96 ± 0.83	1.29, 1.77	12.78	-2.3		HER	3.92 ± 0.76	1.40, 1.80	15.84	-2.6	
	HEXT	3.22 ± 0.69	0.59, 0.99	7.92	-1.3		HEXT	3.21 ± 0.66	0.73, 1.05	11.16	-1.6	
	HAB	3.80 ± 1.01	1.08, 1.65	9.76	-1.7		HAB	3.62 ± 0.89	2.68, 3.20	22.84	-1.9	

Abbreviations: HAB, hip abduction; HER, hip external rotation; HEXT, hip extension.

^a The WB assessments (squat-bilateral, squat-unilateral, and lunge) were each compared with the NWB assessments (HER, HEXT, and HAB).

^b Indicates difference from the WB assessment on the same leg (P = .04); all other WB versus NWB comparisons: P < .01.

tested simultaneously during the SQ-U than when tested unilaterally in separate trials. Because participants could resist the force equally with both limbs during the SQ-B, they may have been able to maintain their center of gravity more easily than during the SQ-U. When resisting during a unilaterally tested limb, they may have shifted their weight differently than during the SQ-B because of different demands to stabilize and maintain balance. We did not examine this stabilization strategy, and therefore, its effects on our results were unclear. It is also important to mention that this may be similar to how the contralateral limb develops tension during unilateral isometric testing. regardless of position.¹⁵ Last, because the LNG position had the highest hip- and knee-flexion angles, the muscles were further challenged to both maintain balance and resist an external load, hence explaining the low strength values we found.

To our knowledge, only 2 previous investigators have examined strength in WB and NWB positions in a similar manner. Lee and Powers⁸ evaluated NWB HAB in a standing-squat test, whereas we studied both the dominant and nondominant limbs, multiple NWB hip-strength assessments, and 3 ways of measuring WB strength. Our strength values for SQ-B and SQ-U were higher than those reported by Lee and Powers⁸ (3.0 \pm 0.6 and 2.6 \pm 0.5 N/kg for males and females, respectively) for their WB hip-

abductor and external-rotator tests. The different results between the 2 studies might be due to variations in the participants and procedures. Our sample consisted of 51 female athletes actively involved in sports, whereas Lee and Powers⁸ studied 20 adults (10 males, 10 females) of unknown training status with a mean age of 30 years. Additionally, our force application was different. The test positions in both studies were identical (30° of hip flexion and 50° of knee flexion); however, Lee et al⁸ quantified strength using a force transducer connected to a nonstretchable fabric strap and instructed participants to push outward as hard as possible in a "make test." Conversely, we quantified strength using HHDs, with participants resisting a force just proximal to the knee joint via eccentric break tests. These procedural differences and the known greater ability to produce force eccentrically should account for the increased strength values observed.

This study involved middle school, high school, and collegiate female athletes who participated in basketball, soccer or volleyball. Hence, these findings may be unique to young, female athletes, which may limit generalization of the results to other populations and constitute a limitation. No participant was able to overcome the examiner's force and, therefore, each trial was actually a break test. In some situations, the participant may be able to fully resist (ie, hold the position isometrically). Further

Table 2.	Correlations and	R ² Values Betweer	Weight-Bearing	(WB) and Non-	-Weight-Bearing	(NWB)	Assessments
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	Domi	nant Limb			Nondominant Limb						
WB	NWB	r	R ²	P Value	WB	NWB	r	R ²	P Value		
Squat-bilateral	HER	0.419	0.18	.002	Squat-bilateral	HER	0.511	0.26	<.001		
	HEXT	0.347	0.12	.013		HEXT	0.361	0.13	.009		
	HABD	0.402	0.16	.003		HABD	0.310	0.10	.027		
Squat-unilateral	HER	0.547	0.30	<.001	Squat-unilateral	HER	0.556	0.31	<.001		
	HEXT	0.426	0.18	.002		HEXT	0.477	0.23	<.001		
	HABD	0.481	0.23	<.001		HABD	0.530	0.28	<.001		
Lunge	HER	0.236	0.06	.096	Lunge	HER	0.368	0.14	.008		
	HEXT	0.310	0.10	.027	-	HEXT	0.525	0.28	<.001		
	HABD	0.269	0.07	.056		HABD	0.183	0.03	.198		

Abbreviations: HAB, hip abduction; HEXT, hip extension; HER, hip external rotation.

examination of WB strength assessment is warranted to better understand the clinical applications for multiple age and sex groups. Also, the examiner's force and sex⁹ are known to affect the outcome of testing via HHDs, and some amount of systematic bias is present.^{19,20} Because the results may be highly dependent on the examiner's force, attempts at recreating our work may yield various results. Additionally, we did not measure electromyographic activity, so it was not possible to assess the activation of specific muscles in each novel WB assessment. However, strength-assessment positions were chosen based on previous research, as outlined in the Methods. Randomization of the strength assessments was not possible, which may have caused unknown effects of physical or mental fatigue (or both) on the outcomes. We encourage future researchers attempting similar methods to fully randomize all testing procedures. Readers should consider all of these limitations when trying to interpret or apply these tests clinically.

The WB assessments are easy to administer and low in cost, and they open doors to future examinations of the relationships between test positions and possibly faulty biomechanics or injury risk. The novel WB tests we presented here may provide additional clinical utility and information, but how they affect lower extremity injury risk is yet to be determined. It remains unclear which combinations of strength and functional assessments are best for clinicians; however, our results may provide additional insight into clinically relevant approaches that are valuable for athletic training practice.

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