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Normalization Considerations for Using the Unilateral Seated Shot Put Test in Rehabilitation

STUDY DESIGN: Cross-sectional study.

OBJECTIVES: To examine the effect of different normalization methods on unilateral seated shot put test results.

BACKGROUND: The unilateral seated shot put test could assist clinical decision making in upper extremity rehabilitation, but test results must be normalized to compare across patients. The effect of normalization methods based on body size and upper-limb dominance is unknown.

METHODS: One hundred twenty-five collegiate athletes (63 males) performed the unilateral seated shot put test with each upper extremity. Anthropometric measures (height, body mass, arm length) and distance thrown were recorded. Normalization based on body size included ratio scaling and allometric scaling. Ratio scaling was performed with the anthropometric measure having the highest correlation to distance thrown (distance/anthropometric measure). Allometric scaling was performed with body mass raised to the theoretical exponent 0.67 (distance/body mass$^{0.67}$) and a derived exponent. Correlations of nonnormalized and normalized values with body mass were then determined. The limb symmetry index [(dominant-side distance/nondominant-side distance) × 100] was used for normalization based on limb dominance. Sex differences were examined.

RESULTS: Body mass was selected for ratio scaling, and 0.35 was the derived allometric-scaling exponent. Across sexes, only allometric scaling with the exponent 0.35 removed the correlation with body mass. The mean limb symmetry index exceeded 100% in males (108.7%) and females (104.4%). All normalized test results were higher in males.

CONCLUSION: When using the unilateral seated shot put test in rehabilitation, allometric scaling with the exponent 0.35 is preferable, limb comparisons should account for 5% to 10% better performance on the dominant side, and performance benchmarks should be set within sex.
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KEY WORDS: *allometric scaling, functional performance testing, limb symmetry index, return to sport, upper extremity*

Functional performance testing is often used in lower extremity rehabilitation to help determine a patient's readiness to return to sports participation.[2,11,25,28] Hopping or jumping tasks are most commonly used,[3,18,25,28] but other types of tasks also exist.[2,15] Functional performance tests impart high forces to an injured joint or body segment that may more closely replicate the forces experienced in sport. Consequently, these tests can reveal impairments in muscle force generation or proprioception and neuromuscular control that might not be obvious with other clinical measures.[7,19] Several studies have found that lower extremity functional performance test results predict future functional outcome,[1,8,12,21,22] indicating their usefulness in lower extremity rehabilitation.

Functional performance testing is not standard in upper extremity rehabilitation and is absent from most upper extremity rehabilitation protocols.[5,23,27] The lack of functional performance testing occurs in spite of several functional performance tests described for the upper extremity.[4,6,17,24] A dearth of research to guide the selection and implementation of upper extremity functional performance tests may be a barrier to more widespread clinical use.

The unilateral seated shot put test is an upper extremity functional performance test with many appealing aspects for clinical use. The test requires pushing a weighted ball forward in a shot put motion.[16] The test requires little equipment and would therefore be easy to administer in most clinical settings. Distance thrown on the unilateral seated shot put test has shown positive correlation with distance on a softball throw, providing external validity.[17] Moreover, in a sample

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of recreationally active adults, test-retest reliability was found to be excellent.[16] Previous studies have not normalized unilateral seated shot put test results,[16,17] which is problematic for implementing the test in clinical settings. Normalization is necessary to compare rehabilitation outcomes across patients and to create benchmarks for rehabilitation progression.[7,10] Normalization for body size (eg, mass or height) is needed, because body size varies between patients and can affect functional performance test results.[9] In addition, rehabilitation progress is often gauged by comparing performance of the injured side to that of the uninjured side. Therefore, understanding the effect of normalization methods based on body size and side is an important step toward using the unilateral seated shot put test in upper extremity rehabilitation.

Normalization for body size can be accomplished with ratio scaling or allometric scaling. Ratio scaling is a common normalization method that involves dividing the test result by an anthropometric measure, such as body mass or height.[26] Ratio scaling is appropriate when the relationship between body size and test performance is linear, but is inadequate for many functional performance tests in which the relationship between body size and test performance is nonlinear.[9,10] Allometric scaling involves dividing the test result by an anthropometric measure raised to an exponent that accounts for the relationship between body size and test performance.[10,26] For example, it has been determined that raising body mass to the exponent 0.67 removes the effect of body size on performance of tests that involve exerting force against an external object.[9] Allometric scaling is thus superior to ratio scaling for normalizing to body size in many functional performance tests.

In clinical settings, normalization based on side is usually accomplished with the limb symmetry index. The limb symmetry index is created by dividing performance on the injured side by performance on the uninjured side and expressing the results as a percentage.[3] The uninjured side is used to represent an individual's performance capacity, and a limb symmetry index close to 100% indicates that the injured and uninjured limbs perform similarly (ie, the injured limb is back to "normal"). However, distance thrown on the unilateral seated shot put test has been found to be higher on the dominant side in the uninjured state,[16] which could affect the interpretation of the limb symmetry index in rehabilitation. For example, if the dominant side is normalized to the nondominant side, the limb symmetry index might be greater than 100% in the uninjured side. An injury to the dominant side could reduce unilateral seated shot put test performance and produce a limb symmetry index close to 100%, but symmetry may not be the appropriate performance target.

The purpose of this study was to examine the effect of different normalization methods on unilateral seated shot put test results. For normalization based on body size, we hypothesized that allometric scaling would be superior to ratio scaling in removing the effect of body size on performance. For normalization based on upper-limb dominance, we hypothesized that the limb symmetry index would indicate better performance on the dominant side. Males and females were analyzed separately based on known differences in body size and functional performance test results. Sex differences in normalized test results were also examined. Obtaining this information may facilitate use of the unilateral seated shot put test for return-to-sport decision making in upper extremity rehabilitation.

METHODS

Participants

Eligible participants were Division I collegiate male and female athletes who participated in routine preparticipation testing at the University of Florida Orthopaedics and Sports Medicine Institute between January and July 2011. Athletes from a variety of sports were included to create robust findings. The exclusion criteria for this study were history of shoulder dislocation, upper extremity surgery in the past 6 months, upper extremity injury in the past month, and upper extremity pain at the time of testing. Adult participants gave written informed consent on a form approved by the University of Florida Institutional Review Board. Minor subjects gave assent, and their parents gave consent, on the same form.

Testing Protocol

The entire sports preparticipation testing protocol included the collection of demographic information and a variety of postural, joint motion, muscle strength, muscle flexibility, performance, and movement analysis measures. This study specifically involved collection of demographic information and performance on a modified version of the unilateral seated shot put test.

The demographic variables used in this study were age, sex, height (centimeters), body mass (kilograms), arm length, arm dominance, sport, and position played. Height and body mass were obtained from the records of athletic trainers. The dominant arm was defined as the preferred limb for throwing a ball. Body mass index was calculated according to a standard formula (kg/m^2). Arm length was measured in centimeters from the tip of the acromion to the styloid process with a standard tape measure by a single tester. A pilot study in which arm length was measured on both sides of 10 subjects at 2 time points separated by 2 to 3 days showed acceptable intrarater reliability for this measure (intraclass correlation coefficient model 3,1 averaged between sides = 0.981).

To perform the unilateral seated shot put test, participants sat with their back against a wall, knees bent at a right angle, and feet flat on the floor (**FIGURE 1**). This position has been described for the 2-hand seated shot put test,[14] whereas a long-sitting position with buttocks and feet supported by chairs and a strap placed

around the chest has been described for the unilateral seated shot put test.[16,17] Requiring contact between the back and the wall provided trunk stabilization without the need for a chest strap. Participants were positioned next to a doorway to allow unrestricted arm motion on the test side. Participants held a 2.72-kg medicine ball at shoulder height and were instructed to push the ball (not throw it) as far forward as possible, keeping their head, scapula on the nontest side, and back in contact with the wall and their nonthrowing arm in their lap. Verbal encouragement was given to facilitate maximal effort, and verbal cues were given for maintaining proper form. The right side was tested first, followed by the left side. Two strips of tape placed 91.4 cm apart were positioned on the floor directly in front of the participant to guide throws. Participants were given 2 practice trials, one at 75% effort and one at 100% effort, with 20 to 30 seconds of rest between each trial while the ball was returned to the athlete. Practice trials were followed by 3 maximal-effort trials, again with a rest between each throw. Distance was measured from the wall to the site of ball contact with the floor, and the results of the 3 maximal-effort trials were averaged together.

Data Analysis

Data were analyzed with SPSS Version 21 (IBM Corp, Armonk, NY). Descriptive statistics were calculated for demographic and unilateral seated shot put test variables. Significance for all analyses was set at $P<.05$.

The anthropometric measures considered for ratio scaling included body mass, which is commonly used for ratio scaling, as well as height and arm length, because they have potential to be associated with the results of this type of functional performance test.[13] Pearson product-moment correlation coefficients were determined between the anthropometric measures and unilateral seated shot put test performance in both sexes, and the measure with the highest correlation was selected for ratio scaling. The dominant and nondominant sides were examined separately, and in the case of a discrepancy in results, the dominant side was given preference. Ratio scaling was performed according to the formula of distance (cm)/anthropometric measure.

FIGURE 1. Unilateral seated shot put test position.

Body mass was the anthropometric measure used for allometric scaling. Both body mass and height have been used for allometric scaling performance on tests that involve exerting force on external objects, but body mass has a higher association with performance.[13] The exponent 0.67 was used [distance (cm)/body mass (kg)]$^{0.67}$ based on theoretical considerations for functional tests that require muscle force or power.[10] The unilateral seated shot put test also involves rapid limb movement, and the theoretical allometric-scaling exponent for these tests is zero (no normalization for body size).[13] Because of the range between these 2 exponents, the allometric scaling exponent was derived in both sexes using the process described by Jaric and colleagues.[10] Body mass and the distance thrown on the dominant and nondominant sides were log-transformed, and then scatter plots were created with the log-transformed values. The slope of the regression equation for each scatter plot was considered the allometric-scaling exponent.

The limb symmetry index was computed for normalization based on limb dominance. The limb symmetry index was computed using raw values for unilateral seated shot put test performance, using the formula (distance thrown on the dominant side/distance thrown on the nondominant side) × 100.

The effect of the different normalization methods on unilateral seated shot put test results was examined in each sex separately. First, Pearson correlation coefficients were calculated between body mass and nonnormalized, ratio-scaled, and allometric-scaled values on the dominant side, to determine the ability of the normalization methods to remove the effect of body size. The limb symmetry index was examined to determine the effect of side. Sex differences in raw, ratio-scaled, and allometric-scaled values on the dominant side were compared with a general linear model with repeated measures, and the limb symmetry index was compared with an independent-samples t test.

RESULTS

A total of 125 participants (63 males and 62 females) from 6 different sports participated in the study. Football players comprised the largest percentage of the sample (38.4%). Most of the participants in the sample (87.2%) were right-hand dominant. Demographic information for the sample can be found in **TABLE 1**.

In both male and female athletes, body mass had the highest correlation with distance thrown on the dominant side when compared to the other anthropometric measures (**TABLE 2**). In male athletes, body mass also had the highest correlation with distance thrown on the nondominant side. But in female athletes, body mass and height had similar correlations with distance thrown on the nondominant side (**TABLE 2**). Based on these results, body mass was selected for ratio scaling.

Scatter plots used to derive the allometric-scaling exponent are shown in **FIGURE 2**. As expected, the log-transformed values of body mass were positively correlated with log-transformed values of distance thrown in both male and female athletes ($P<.05$). Allometric-scaling ex-

TABLE 1 Demographic and Anthropometric Data Organized by Sport*

	Men's Football (n = 48)	Men's Baseball (n = 15)	Women's Basketball (n = 13)	Women's Lacrosse (n = 27)	Women's Softball (n = 11)	Women's Volleyball (n = 11)
Age, y	19.4 ± 1.1	20.3 ± 1.2	20.7 ± 1.5	19.8 ± 0.9	19.3 ± 1.0	20.3 ± 1.1
Height, cm	186.7 ± 7.0	188.3 ± 5.3	179.4 ± 9.1	166.7 ± 5.3	173.9 ± 7.5	178.8 ± 8.6
Weight, kg	104.1 ± 19.2	93.2 ± 10.2	72.2 ± 8.5	62.8 ± 5.8	75.6 ± 11.5	72.6 ± 7.4
BMI, kg/m^2	29.7 ± 4.2	26.3 ± 3.0	22.4 ± 1.2	22.6 ± 1.6	24.9 ± 2.8	22.7 ± 1.8
Arm length, cm†	59.7 ± 3.0	60.0 ± 3.3	56.9 ± 3.4	51.3 ± 2.2	54.4 ± 1.8	58.5 ± 4.7
Hand dominance, n						
Right	45	11	11	22	10	10
Left	3	4	2	5	1	1
Sport position, n	Quarterback, 3; defensive back, 11; wide receiver, 6; linebacker, 5; defensive tackle, 3; running back, 4; tight end, 4; defensive end, 4; punter, 1; offensive lineman, 7	Pitcher, 15	Guard, 8; center, 2; forward, 3	Goalkeeper, 2; attack, 10; defense, 7; midfield, 8	Pitcher, 3; utility, 4; infield, 3; outfield, 1	Middle blocker, 3; outside hitter, 2; libero, 1; defensive specialist, 3; setter, 2

Abbreviation: BMI, body mass index.
**Values are mean ± SD unless otherwise indicated.*
†Average of dominant and nondominant arms.

ponents ranged from 0.28 on the nondominant side in male athletes to 0.45 on the dominant side in female athletes. The mean value of the slopes across sexes and sides was 0.35, which was used as the derived allometric-scaling exponent.

Nonnormalized, ratio-scaled, and allometric-scaled values of unilateral seated shot put test performance across sports can be found in **TABLE 3**. Mean distance thrown was greater on the dominant side compared to the nondominant side (t = 8.429, P<.001), creating a mean limb symmetry index that exceeded 100% (range, 103.2%-110.8% across sports; 95% confidence interval: 105.2%, 108.0%).

Nonnormalized, ratio-scaled, and allometric-scaled values on the dominant side of male and female athletes are found in **TABLE 4**. In both sexes, body mass was positively correlated with nonnormalized values (P<.001), negatively correlated with ratio-scaled values (P<.001), and negatively correlated with allometric-scaled values using the exponent 0.67 (males, P<.001; females, P = .061). There was no significant association between body mass and allometric-scaled values using the exponent 0.35 in either sex (males, P = .654; females, P = .322). The comparison of nonnormalized, ratio-scaled, and allometric-scaled values between sexes revealed a significant group-by-measure interaction (P<.001). Although all values were higher in males compared to females (P<.001), the magnitude of difference

TABLE 2 Correlation Coefficients Between Anthropometric Measures and Unilateral Seated Shot Put Test Performance on the Dominant and Nondominant Sides*

	Distance-D	Distance-ND	Body Mass	Height	Arm Length
Male athletes					
Distance-D, cm	...	0.664	0.572	0.388	0.292
Distance-ND, cm		...	0.530	0.469	0.389
Body mass, kg			...	0.579	0.449
Height, cm				...	0.755
Arm length, cm†					...
Female athletes					
Distance-D, cm	...	0.862	0.476	0.448	0.369
Distance-ND, cm		...	0.382	0.385	0.304
Body mass, kg			...	0.762	0.662
Height, cm				...	0.916
Arm length, cm†					...

Abbreviations: Distance-D, unilateral seated shot put test performance on the dominant side; Distance-ND, unilateral seated shot put test performance on the nondominant side.
**All correlation coefficients were significant (P<.05).*
†Average of the dominant and nondominant arms.

was greatest for nonnormalized values (276.0 cm) and least for ratio-scaled values (1.3 cm/kg). As shown in **TABLE 4**, the limb symmetry index was higher in males than in females (males, 108.7%; females, 104.4%; $P = .002$).

DISCUSSION

This study was undertaken to increase knowledge about methods for normalizing unilateral seated shot put test results to facilitate the use of this test in upper extremity rehabilitation. Only allometric scaling with the exponent 0.35 removed the influence of body mass on performance. Across the sample, performance was better on the dominant side than on the nondominant side, creating a mean limb symmetry index of 106.6%. The limb symmetry index was slightly higher in males than in females, and male athletes threw farther than female athletes. Based on these data, we recommend that, when using the unilateral seated shot put test in rehabilitation, allometric scaling with the exponent 0.35 be used to normalize to body size, comparisons to the uninjured limb be interpreted with consideration of limb dominance, and distance benchmarks be set for each sex separately.

To the best of our knowledge, this is the first study to investigate methods for normalizing unilateral seated shot put test results. The goal of normalization in clinical settings is to eliminate the effect of body size on performance so that rehabilitation targets can be interpreted across patients. As expected, nonnormalized test results were positively correlated with body mass. Results of ratio scaling to body mass and allometric scaling to body mass raised to 0.67 were both negatively correlated with body mass, suggesting that both of these methods overestimate the effect of body size on performance. The derived exponent for allometric scaling was 0.35, which falls in between exponent values of zero (no normalization, used for tests of rapid movement) and 0.67 (used for tests of muscle strength and power).[10] The value of the derived exponent may reflect the fact that the weight and inertia of the ball were relatively small and allowed muscles to develop maximum strength and power as well as for the limb to move rapidly. Allometric scaling with the exponent 0.35 removed the correlation between unilateral seated shot put test results and body mass, achieving a body size–independent measure. Future research in other samples is needed to confirm the value of the derived allometric-scaling exponent.

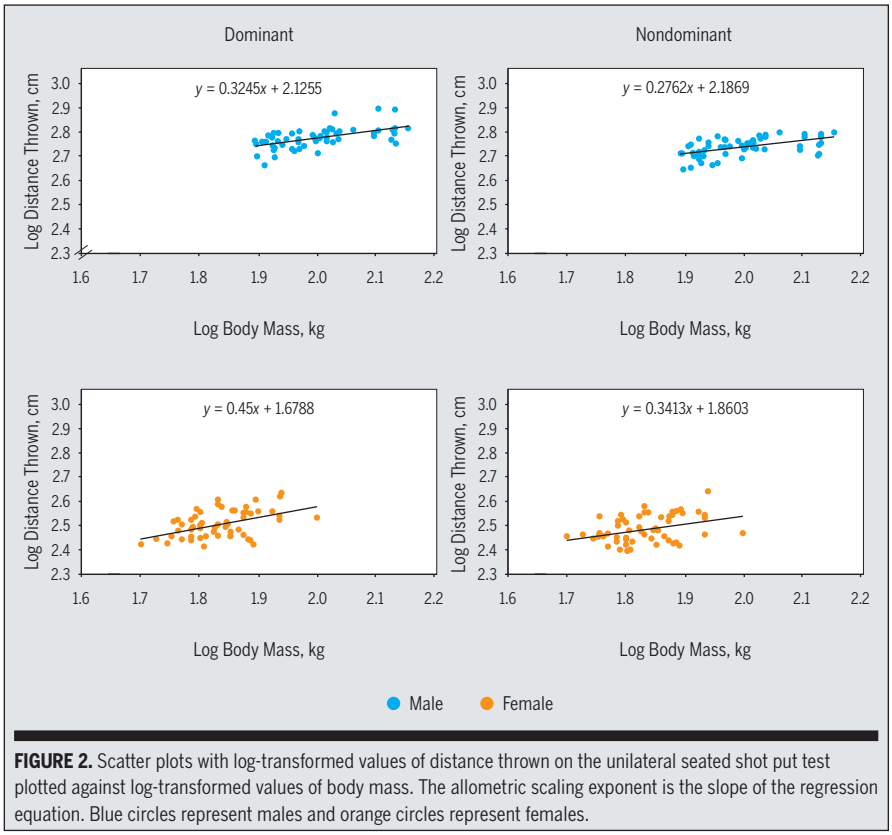

FIGURE 2. Scatter plots with log-transformed values of distance thrown on the unilateral seated shot put test plotted against log-transformed values of body mass. The allometric scaling exponent is the slope of the regression equation. Blue circles represent males and orange circles represent females.

Based on mean values, the dominant upper extremity threw farther than the nondominant upper extremity, regardless of sport. Better performance on the dominant side agrees with other research on the unilateral seated shot put test[16] and with the fact that the dominant upper extremity tends to have more coordinated movement than the nondominant upper extremity.[20] Performance differences based on limb dominance must be considered when setting targets for the unilateral seated shot put test in rehabilitation. In lower extremity rehabilitation, a limb symmetry index of 100% is often considered to be ideal, and targets of 85% or 90% have been required for clearance to return to sport participation.[25] However, the results of this study suggest that it may be acceptable for an injured nondominant upper extremity to have slightly lower performance than the dominant upper extremity; conversely, it may be expected for the injured dominant upper extremity to achieve better performance than the nondominant upper extremity. The consequences of not achieving a limb symmetry index near 106% cannot be determined from this study. The magnitude of the asymmetry was found to be slightly but significantly higher in males than in females. Because the study included males from only 2 sports compared to females from 4 sports, the differences in asymmetry might have been influenced by sports representation. It is possible that baseball and football place

TABLE 3 Nonnormalized and Normalized Unilateral Seated Shot Put Test Results in Each Sport*

	Men's Football (n = 48)	Men's Baseball (n = 15)	Women's Basketball (n = 13)	Women's Lacrosse (n = 27)	Women's Softball (n = 11)	Women's Volleyball (n = 11)
Nonnormalized, cm						
Dominant	597.8 ± 64.6	596.9 ± 28.3	365.8 ± 36.5	296.4 ± 22.9	342.5 ± 23.3	310.7 ± 45.8
Nondominant	553.4 ± 47.3	541.8 ± 44.7	351.0 ± 35.6	287.7 ± 20.8	325.1 ± 24.3	292.6 ± 41.9
Ratio scaled, cm/kg						
Dominant	5.9 ± 0.8	6.5 ± 0.6	5.1 ± 0.5	4.8 ± 0.5	4.6 ± 0.7	4.3 ± 0.6
Nondominant	5.4 ± 0.8	5.9 ± 0.6	4.9 ± 0.5	4.6 ± 0.5	4.4 ± 0.8	4.0 ± 0.5
Allometric scaled, cm/kg$^{0.67}$						
Dominant	27.3 ± 2.7	29.2 ± 2.0	21.1 ± 1.8	18.8 ± 1.7	19.4 ± 2.2	17.9 ± 2.5
Nondominant	25.3 ± 2.5	26.4 ± 2.0	20.3 ± 1.7	18.3 ± 1.7	18.4 ± 2.7	16.8 ± 2.0
Allometric scaled, cm/kg$^{0.35}$						
Dominant	118.0 ± 11.0	122.3 ± 5.6	81.8 ± 6.8	69.7 ± 5.4	75.7 ± 6.2	69.4 ± 9.6
Nondominant	109.4 ± 8.0	110.9 ± 7.7	78.5 ± 6.6	67.7 ± 5.3	72.0 ± 7.7	65.3 ± 8.2
Limb symmetry index, %	108.1 ± 7.7	110.8 ± 9.2	104.5 ± 7.5	103.2 ± 6.6	105.7 ± 8.3	106.3 ± 6.4

**Values are mean ± SD.*

TABLE 4 Nonnormalized and Normalized Unilateral Seated Shot Put Test Results on the Dominant Side in Each Sex

	Males (n = 63)*		Females (n = 62)†	
	Results‡	Correlation Coefficient§	Results‡	Correlation Coefficient§
Nonnormalized, cm	597.6 ± 57.8	$r = 0.572$[‖]	321.6 ± 41.4	$r = 0.476$[‖]
Ratio scaled, cm/kg	6.0 ± 0.8	$r = -0.822$[‖]	4.7 ± 0.6	$r = -0.540$[‖]
Allometric scaled, cm/kg$^{0.67}$	27.7 ± 2.6	$r = -0.597$[‖]	19.2 ± 2.2	$r = -0.239$
Allometric scaled, cm/kg$^{0.35}$	119.0 ± 9.3	$r = -0.058$	73.3 ± 8.2	$r = 0.128$
Limb symmetry index, %	108.7 ± 8.1	$r = 0.133$	104.4 ± 7.0	$r = 0.205$

**Baseball and football athletes.*
†Basketball, lacrosse, softball, and volleyball athletes.
‡Values are mean ± SD.
§Correlation coefficients represent the association of the variable with body mass (kg).
‖Measure is significantly associated with body mass (P<.001).

greater emphasis on power production in the dominant upper extremity compared to other sports, such as basketball or swimming. Moreover, based on work by Negrete and colleagues,[16] the magnitude of asymmetry may be comparable in recreationally active males and females (males, 113%; females, 110%).

The testing procedure described in this study isolates performance to the upper extremity and therefore is not the same as a typical throwing motion. The throwing motion is a highly skilled movement, and mimicking the throwing motion would give throwing athletes a performance advantage. This functional performance test has potential to be useful in upper extremity rehabilitation for athletes in sports that require upper extremity power production during training, competition, or conditioning, or for people with jobs that require upper extremity power production (eg, manual laborers).

The main strength of this study is that it included a large sample of competitive athletes with almost equal distribution between the sexes. Thus, significant insight is gained into normalization methods and normative values for the unilateral seated shot put test. A limitation, though, is that the findings may not generalize to sports other than those included in this study and to recreational athletes. Continued research is necessary to develop the unilateral seated shot put test for use in upper extremity rehabilitation. Specifically, the unilateral seated shot put test will need to be applied in a patient population with shoulder, elbow, or wrist/hand injuries. At this time, it is unknown whether performance on the test is sensitive to impairments after injury (eg, pain, muscle weakness, or loss of joint motion) or whether other joints in the kinetic chain can compensate. In addition, prospective studies are needed to evaluate whether performance on this test is associated with self-report of function or future injury. The current study should be considered a platform for future clinical research.

CONCLUSION

This study found that dividing unilateral seated shot put test results by body mass raised to the ex-

ponent 0.35 ($cm/kg^{0.35}$) is an appropriate method of normalizing to body size. The limb symmetry index is often used in clinical settings to normalize to side, but the limb symmetry index should be interpreted carefully for the unilateral seated shot put test, because asymmetry can exist up to 10% of performance in favor of the dominant arm. Distance benchmarks should be set separately for male and female athletes. ◉

KEY POINTS

FINDINGS: Only allometric scaling with the exponent 0.35 removed the influence of body mass on unilateral seated shot put test results. Performance is higher on the dominant side and in males.

IMPLICATIONS: Unilateral seated shot put test results should be normalized to body mass raised to the exponent 0.35, comparisons between limbs should be done cautiously and with respect to limb dominance, and performance benchmarks should be set within sex.

CAUTION: These results might not be generalizable to a less athletic population or athletes who participate in different sports.

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