

A Bilateral Comparison of the Underlying Mechanics Contributing to the Seated Single-Arm Shot-Put Functional Performance Test

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Context: Functional performance tests (FPTs) are tools used to assess dynamic muscle strength and power. In contrast to the lower extremity, fewer FPTs are available for the upper extremity. The seated single-arm shot put test has the potential to fill the void in upper extremity FPTs; however, the underlying mechanics have not been examined and, therefore, the validity of bilateral comparisons is unknown.

Objective: To examine the effects of upper extremity dominance and medicine-ball mass on the underlying mechanics of the seated single-arm shot put.

Design: Crossover study.

Setting: Biomechanics laboratory.

Patients or Other Participants: Fifteen women (age = 23.6 ± 2.1 years, height = 1.65 ± .07 m, mass = 68.1 ± 11.7 kg) and 15 men (age = 24.3 ± 4.0 years, height = 1.80 ± 0.06 m, mass = 88.1 ± 16.4 kg), all healthy and physically active.

Intervention(s): Seated single-arm shot-put trials using the dominant and nondominant limbs were completed using three 0.114-m-diameter medicine-ball loads (1 kg, 2 kg, 3 kg).

Main Outcome Measure(s): Customized touch-sensitive gloves, synchronized with kinematic data of the hands, signaled ball release, so that release height, release angle, and peak anterior and vertical velocity could be quantified for each trial. In addition, the horizontal range from release to first floor impact was recorded.

Results: The dominant-limb horizontal ranges were 7% to 11% greater ($P < .001$) than for the nondominant limb for each of the 3 ball masses. No bilateral release-height or -angle differences were revealed ($P \geq .063$). Release velocities were 7.6% greater for the dominant limb than the nondominant limb ($P = .001$).

Conclusions: Our results support the use of the seated single-arm shot put test as a way to compare bilateral upper extremity functional performance. The near-identical release heights and angles between the dominant and nondominant limbs support the interpretation of measured bilateral horizontal-range differences as reflecting underlying strength and power differences.

Key Words: elbow, power, shoulder, strength

Key Points

- For the seated single-arm shot-put test using the dominant and nondominant limbs, release heights and angles were nearly identical.
- Dominant-limb release velocities were greater than nondominant measures, resulting in greater horizontal ranges for the dominant limb.
- Horizontal-range differences can be considered reflective of underlying upper extremity strength and power differences.

Functional performance tests (FPTs) are important tools for assessing strength and power deficits. They are used by many health care professionals, particularly athletic trainers, physical therapists, and strength and conditioning specialists, to identify a predisposition to injury, evaluate rehabilitation progress, determine return-to-play status, and quantify strength and power related to optimal physical performance. Optimal FPTs mimic the stresses, loads, and velocities of functional activities in a controlled manner without requiring sophisticated or time-intensive measurements.¹ Normative data can be used to interpret test performance, and FPTs that use a single limb are advantageous because they allow bilateral limb symmetry to be assessed.¹

In contrast to the variety of FPTs available for the lower extremity, such as the single-legged-hop test variations,

few FPTs are available for upper extremity testing. Various closed kinetic chain tests, including push-up variations,² the 1-arm hop for distance,³ and the closed kinetic chain upper extremity stability test,⁴⁻⁶ have been described. Although these reflect important aspects of upper extremity function, many functional tasks, such as throwing and reaching, involve the upper extremity functioning in an open kinetic chain manner. Additionally, many functional tasks involve short bursts of maximal activity⁷; in contrast, several of the aforementioned tests involve sustained submaximal activity. The most commonly studied and used open kinetic chain tests include softball throws for distance^{7,8} and medicine-ball throwing and pressing.⁹⁻¹¹ Because of the strong associations between throwing, coordination, and limb dominance, bilateral comparisons of throwing tasks are difficult. Bilateral medicine-ball presses replicate

functional tasks involving simultaneous pushing activity of both upper extremities. Unfortunately, when single-limb assessments are needed, bilateral medicine-ball presses have limited utility.

The seated single-arm shot-put test might measure each limb's ability to produce a short burst of maximal effort in an open chain manner. In contrast to throwing tasks, the seated pressing or putting movement has an advantage arising from the reduced coordination demands of the task. This may enable practitioners to better isolate upper extremity strength and power independent of coordination. For the seated single-arm shot-put test, the participant adopts a long-seated position against a backrest. Beginning with the upper extremity holding a medicine ball anterior to the shoulder with the elbow adjacent to the torso, the participant attempts to "put" a medicine ball the greatest distance. The initial location of medicine-ball ground contact is measured relative to the starting position and reflects the test limb's underlying functional strength and power. Negrete et al^{7,8} studied seated single-arm shot-put performance using a 2.7-kg medicine ball. They quantified the intraclass reliability coefficients (standard error of measurement) as 0.988 (0.178 m) and 0.971 (0.203 m) for the dominant and nondominant limbs, respectively.⁷ Additionally, they reported 9% bilateral differences favoring the dominant limb⁷ and revealed that the relationships with other upper extremity FPTs, pushups, closed kinetic chain upper extremity stability test, and softball throw ranged from 0.44 to 0.66.⁸ Projectile mechanics suggest that 3 underlying factors—release height, release angle, and release velocity—may confound the measurement of the horizontal range (distance) the ball is projected. Similar horizontal ranges may be achieved using different underlying projection mechanics, which may complicate comparisons of bilateral and normative data and interpretation of the test in terms of underlying upper extremity functional strength and power. Also, the optimal ball mass to use for the seated single-arm shot-put test has yet to be determined. An initial investigation¹² of a standing single-arm shot-put test demonstrated a significant 10% to 15% decrease in horizontal range as ball mass increased by 1 kg. Thus, the degree to which the underlying mechanics are different between medicine balls of various masses during the seated single-arm shot put test is unknown. Therefore, the purpose of our research was to examine the effects of upper extremity dominance and medicine-ball mass on projectile mechanics of the underlying seated single-arm shot put.

METHODS

Participants

Fifteen women (age = 23.6 ± 2.1 years, height = 1.65 ± .07 m, mass = 68.1 ± 11.7 kg) and 15 men (age = 24.3 ± 4.0 years, height = 1.80 ± .06 m, mass = 88.1 ± 16.4 kg) volunteered and completed all study procedures. All participants were *physically active*, defined as being involved in some form of physical exercise at least 3 times per week for a minimum of 30 minutes per session. They provided lists of typical weekly physical activities (types and lengths). Potential participants were screened for precluding health-related factors via a medical questionnaire. Exclusion criteria were cervical spine, shoulder,

elbow, or wrist injury within the past 6 months; regular involvement in a sport that emphasized the use of 1 arm over the other (eg, baseball, softball, tennis, volleyball); or surgery to the shoulder or elbow in the past year. The study received institutional review board approval, and before any study procedures began, participants reviewed and signed an institutional review board–approved consent form.

Experimental Design

Initially, all participants underwent a familiarization session in which they were taught the proper seated shot-putting technique. Participants completed enough trials to become comfortable and consistent in performing the test. During the single 45-minute data-collection session, which was scheduled for 24 to 72 hours after the familiarization session, participants completed the seated single-arm shot put with 3 medicine balls of different masses (1 kg, 2 kg, and 3 kg) using both their dominant and nondominant arms (4 trials per ball). To control for any potential multiple exposure or fatigue effects, participants were first randomly assigned an order for the balls of different masses, followed by a limb order. After the first limb completed a trial using the given ball, the contralateral limb performed the trial using the same ball.

Seated Single-Arm Shot-Put Procedures. Before the trials for data collection, participants completed a warm-up exercise bout. First, they performed a 5-minute bout on an upper body ergometer (model Aerobic Ergometer; Cybex, Boston, MA) at a pace corresponding to a rating of perceived exertion between 10 and 12 on the modified Borg scale.¹³ Next, participants were guided through 30 seconds of forward, backward, and horizontal adduction-abduction arm swings. They then completed a progressive 4-trial gradient warm-up of the seated single-arm shot put involving 1 trial of the shot-put maneuver at 25%, 50%, 75%, and 100% of maximal effort using each limb with the first assigned medicine ball.⁷ Participants were given a 2-minute rest period after completing the gradient warm-up and between limb-and-load combinations.^{7,8}

The seated single-arm shot-put technique duplicated the procedures previously described.^{7,8} To begin the test, participants assumed a long-seated position against a backrest (Figure 1). They gripped the ball in their hand while keeping their elbow tucked against their torso and as far back in the backrest as possible. The nontest arm was positioned in his or her lap. While performing the test, participants were instructed to keep their back against the backrest and to not cross the test limb past the midline of the torso. They were also told not to bend their knees during the test. Finally, participants were instructed to avoid any preloading (stretch-shortening) movements with the test limb before beginning the maneuver. Before each recorded test trial, they were orally instructed to "put the medicine ball as hard as you can to obtain the greatest distance." Test trials were repeated if participants crossed the torso midline with their testing arm, moved the torso away from the backrest, bent their knees, or preloaded before completing the test. Each limb completed 4 test trials using each of the 3 ball masses, for a total of 12 trials.

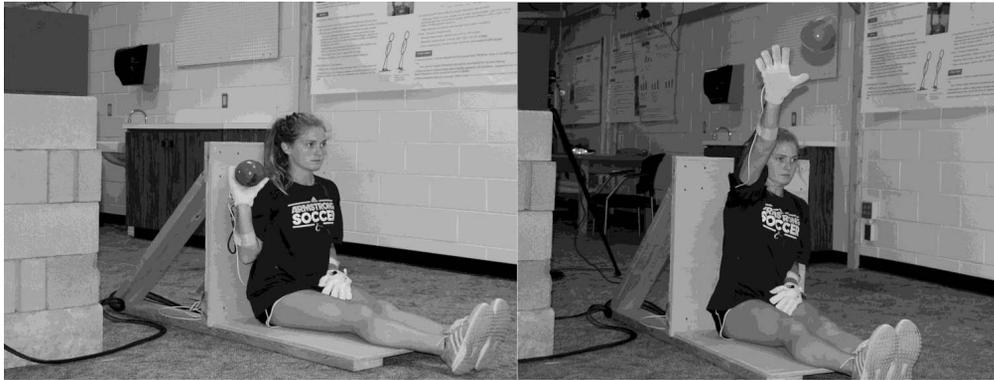


Figure 1. The seated single-arm shot-put test began with the ball held in the hand while keeping the elbow tucked against the torso and as far back to the backrest as possible (left). Participants were then orally instructed to “put the medicine ball as hard as you can to obtain the greatest distance” (right).

Data Collection and Reduction

During each seated single-arm shot-put trial, an extended-range electromagnetic tracking system (model Motion-Star; Ascension Inc, Shelburne, VT) captured kinematic data of the hands and torso using The Motion Monitor (Innovative Sports Training Inc, Chicago, IL) data-collection platform. Electromagnetic receivers were fixed to the dorsal aspect of the hands and seventh cervical vertebra spinous process using a combination of double-sided and surgical tapes. Local axes as well as the hands and torso center of masses relative to the hand and torso sensors were established by digitizing the proximal-superior and distal-inferior hand and torso segment ends using a calibrated stylus. Additionally, each participant wore a custom-designed set of pressure-sensitive gloves during each test trial to indicate ball contact and release.¹⁴ Integrated into the gloves were 6 pressure sensors located at the distal end of the 4 fingers and 2 across the palmar aspects of the metacarpophalangeal joints. The sensors consisted of a neoprene frame with 2 layers of copper fabric separated by 2 layers of Velostat (3M, Maplewood, MN) to form an electrical switch. The 6 sensors were wired in parallel. The parallel combination of the sensors was in series with a 4.7-k Ω pull-down resistor and a 4.5-V battery pack. Pressure applied to a single sensor or multiple sensors produced a signal above 4 V across the pull-down resistor. The voltage across the pull-down resistor was 0 V when pressure was removed from all sensors. The voltage measured across the pull-down resistor could then be used to determine ball-contact and -release times. The signals from the gloves were synchronized and collected simultaneously with the kinematic data via The Motion Monitor. Finally, for each seated single-arm shot-put trial, the location of the first ball’s contact with the ground was marked with a labeled sticker. Upon completion of all test trials, the horizontal range (anterior distance of each test) was measured from the backrest.

Kinematic data reduction was conducted offline using MATLAB-based scripts (The MathWorks Inc, Natick, MA). First, all kinematic data were low-pass filtered with a zero-phase lag Butterworth filter (10-Hz cutoff). Using the synchronized signals from the gloves indicating ball release, 3 variables were computed from the hand with respect to the global axis system. The global axis system location was established on the floor where the vertical

backrest was secured. *Release height* was defined as the vertical position of the hand from the floor at ball release, normalized to body height. *Release angle* was computed as the angle between the hand and the horizontal plane relative to the world axis origin. *Anterior and vertical release velocities* were defined as the peak velocities occurring within 11 frames (0.1 second) before ball release. Each variable was measured over 4 trials with each ball mass and both limbs.

Statistical Analysis

The average of each dependent variable across the 4 trials was computed. After exploratory analysis of the data for normality, we conducted separate 2-factor (limb, ball mass) repeated-measures analyses of variance on the dependent variables of release height, release angle, and horizontal range. A 3-factor (direction, limb, mass) repeated-measures analyses of variance was calculated for the release velocities. When sphericity was violated, we applied the Huynh-Feldt correction. Significant interactions were explored using simple main-effects post hoc comparisons with Bonferroni adjustments. For significant ball-mass effects, post hoc trend analyses were conducted. Limb symmetry indices were computed for the horizontal-range data as the mean score of the dominant limb divided by the mean score of the nondominant limb, expressed as a percentage. Significance for all inferential statistics was set a priori at $\alpha \leq 0.05$. All statistical analyses were conducted using statistical software (SPSS version 21.0; IBM Corp, Armonk, NY).

Additional post hoc descriptive analyses were performed for dominant–nondominant release height and angle differences to fully determine the degree of bilateral symmetry in these variables and allow for horizontal-range influence computations. For each ball mass, 3 scenarios were considered to elucidate how much of an influence the bilateral differences in release height and angle had on the bilateral horizontal-range differences: (1) the mean dominant–nondominant difference, (2) the values that encompassed the middle 75% of the participants, (3) the simultaneous influence of the release height and angles that encompassed the middle 75% of the participants. Horizontal ranges were computed using the following

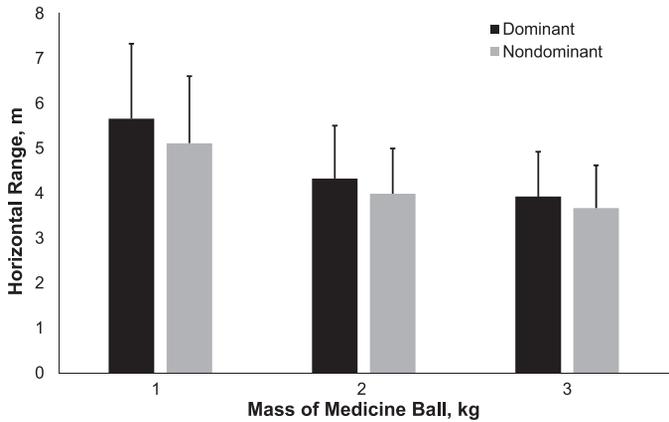


Figure 2. Horizontal range (mean \pm standard deviation) of the dominant and nondominant limbs across the 3 ball masses (1 kg, 2 kg, 3 kg). Both limbs demonstrated significant linear and quadratic trend decreases across ball masses; however, the linear trend was greater for the dominant limb.

equation:

$$\text{horizontal range} = \frac{v^2 \times \sin\theta \times \cos\theta + v_h \times \sqrt{v_v^2 + 2gh}}{g},$$

where v is the average release velocity, θ is the release angle, v_h is the horizontal release velocity, v_v is the vertical release velocity, g is gravitational acceleration, and h is the release height.

RESULTS

Horizontal Range

The horizontal ranges decreased as the medicine ball mass increased (Figure 2); however, the effect was not the same between limbs ($F_{2,58} = 9.35$, $P < .001$). Across the 3 ball masses, the horizontal ranges decreased in a linear manner (dominant limb: $P < .001$, $\eta^2 = 0.84$; nondominant limb: $P < .001$, $\eta^2 = 0.85$); however, significant quadratic trends (dominant limb: $P < .001$, $\eta^2 = 0.66$; nondominant limb: $P < .001$, $\eta^2 = 0.57$) identified larger decreases between the 1-kg and 2-kg ball masses compared with the 2-kg and 3-kg ball masses. Ball mass induced a stronger linear horizontal-range decrease for the dominant limb than the nondominant limb ($P = .001$, $\eta^2 = 0.34$). Horizontal ranges were greater for the dominant limb than the nondominant limb for the 1-kg ($P < .001$, 95% confidence interval [CI] = 0.37, 0.72 m), 2-kg ($P < .001$, 95% CI = 0.22, 0.46 m), and 3-kg ($P < .001$, 95% CI = 0.15, 0.36 m) medicine balls. Despite the significant limb differences, the majority of participants displayed a horizontal-range limb symmetry index of $\pm 15\%$ (Table 1).

Table 1. Horizontal-Range Limb Symmetry Index (Dominant/Nondominant $\times 100$) Descriptive Statistics For the 3 Ball Masses

Ball Mass, kg ^a	Mean \pm SD	Minimum–Maximum	Limb Symmetry Index, % (n)				
			<–15%	–15% to –5%	$\pm 5\%$	5%–15%	>15%
1	110.8 \pm 7.8	94.4–128.2	0 (0)	3.3 (1)	23.3 (7)	46.7 (14)	26.7 (8)
2	108.1 \pm 7.6	84.1–126.2	3.3 (1)	0 (0)	26.7 (8)	46.7 (14)	23.3 (7)
3	107.5 \pm 8.6	83.0–135.4	3.3 (1)	0 (0)	26.7 (8)	60.0 (18)	10.0 (3)

^a At each ball mass, the horizontal range was greater for the dominant limb.

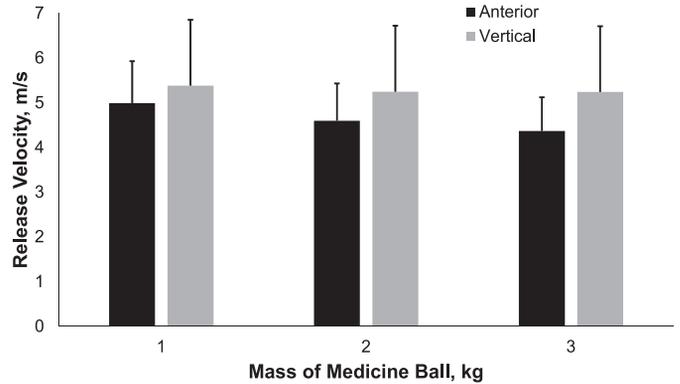


Figure 3. Vertical and anterior ball-release velocities (mean \pm standard deviation), collapsed across limbs, for the 3 ball masses (1 kg, 2 kg, 3 kg). Although ball mass prompted significant decreases in anterior-release velocity, it had no effect on vertical release velocity.

Release Height

Release heights ranged from 47.2% to 48.8% of body height and were statistically equal between the dominant and nondominant limbs ($F_{1,58} = 1.27$, $P = .290$; Table 2). Additionally, release heights were not affected by ball mass ($F_{1,29} = 0.25$, $P = .623$). The limb-by-ball mass interaction was also nonsignificant ($F_{1,7,49,3} = 1.46$, $P = .242$). Across the 3 ball masses, the descriptive bilateral release-height symmetry analyses revealed mean differences ranging between -0.2 and 1.2% body height (-0.004 and 0.021 m), with 77% to 87% of the participants demonstrating release-angle dominant–nondominant differences of less than 10% of body height.

Release Angle

Release angles became smaller ($F_{2,58} = 3.42$, $P = .039$) as ball mass increased in a linear manner ($P = .026$, $\eta^2 = 0.16$; Table 3). The quadratic trend was not significant ($P = .417$, $\eta^2 = 0.02$). Based on the limb ($F_{1,58} = 3.74$, $P = .063$) and interaction ($F_{2,58} = 0.85$, $P = .434$) effects, no differences were present between the dominant and nondominant limbs. Across the 3 ball masses, the descriptive bilateral release-angle symmetry analyses revealed mean differences ranging between 1.8° and 2.5° , with 77% to 80% of the participants demonstrating release-angle dominant–nondominant differences of less than 8° .

Release Velocities

Across the 3 ball masses and 2 directions, release velocity was greater for the dominant limb (5.15 ± 1.34 m/s) than for the nondominant limb (4.78 ± 1.15 m/s; $F_{1,29} = 13.84$, $P = .001$, 95% CI = -0.16 , 0.57 m/s). Ball mass (Figure 3) influenced the anterior- and vertical-release velocities

Table 2. Release Heights Between the Limbs for Ball Masses

Ball Mass, kg	Release Height, %BH (Mean ± SD)		Dominant–Nondominant Difference ^a	
	Dominant	Nondominant	Mean ± SD (%BH)	Participants Within ±10%BH, % (n)
1	47.3 ± 5.2	47.5 ± 5.7	-0.2 ± 8.1	77 (23)
2	48.5 ± 5.7	47.5 ± 5.6	0.9 ± 6.8	87 (26)
3	48.8 ± 6.3	47.6 ± 5.5	1.2 ± 7.3	87 (26)

Abbreviation: BH, body height.

^a Positive dominant–nondominant differences favored a greater release height for the dominant limb.

differently ($F_{1,4,42.0} = 9.98$, $P = .001$). As ball mass increased, the anterior-release velocity decreased in both a linear ($P < .001$, $\eta^2 = 0.68$) and a quadratic ($P < .001$, $\eta^2 = 0.36$) manner. Neither the linear ($P = .156$, $\eta^2 = 0.07$) nor the quadratic ($P = .486$, $\eta^2 = 0.02$) trends were significant for the vertical-release velocity.

Computed Effects of Bilateral Release Height and Angle Differences on Horizontal Ranges

The computed effects of the dominant–nondominant release-height and -angle differences showed that release height had a negligible influence, whereas release angle had a moderate influence (Table 4). Influence of the release height and angle considered simultaneously was slightly larger than that of the release angle alone. With the exception of the 3-kg ball mass, when compared with the actual measured bilateral horizontal-range differences, the simultaneous influences of release height and angle were approximately half of the measured bilateral horizontal-range differences. For example, the measured bilateral horizontal-range difference for the 2-kg ball was 0.54 m, which exceeded the computed simultaneous 0.26-m influence of release height and angle.

DISCUSSION

The primary purpose of our study was to compare the underlying projectile mechanics between the dominant and nondominant extremities during the seated single-arm shot-put test. Establishing similar underlying mechanics, specifically release heights and angles, would support using the single-arm shot-put test for bilateral upper extremity functional performance assessments. Although the dominant limb demonstrated greater release velocity compared with the nondominant limb, release heights and angles were similar bilaterally. Thus, the greater horizontal range for the dominant limb is likely explained by the release-velocity differences, which can most likely be attributed to greater functional muscle strength and power in the dominant limb. From a clinical perspective, these data support using the seated single-arm shot-put test to conduct bilateral upper extremity FPTs.

Previous researchers^{7,15} considered seated single-arm shot-put performance using a single medicine ball (2.72 kg) with a larger diameter than the 3 medicine balls we used. In addition to medicine balls with different masses and diameters, the variability in the horizontal-range scores across the various participant activity groups revealed by Chmielewski et al¹⁵ makes direct comparison of our raw scores with the previous reports difficult. It is also important to note a difference in procedures between the studies. Both the participants in the study by Chmielewski et al¹⁵ and our participants performed the seated single-arm shot put in a long-seated position on the floor, but Negrete et al⁷ seated their participants in an elevated chair. Based purely on a projectile-mechanics perspective, the elevated position should increase release height, which should subsequently increase the horizontal range of the ball. However, despite the theoretical advantage of elevated release height, the horizontal ranges of Negrete et al⁷ were less than those of both Chmielewski et al¹⁵ and our participants. Furthermore, close inspection of the data of Negrete et al⁷ revealed higher intersubject variability, approximately 50% of the mean for both sexes and limbs, than either the data of Chmielewski et al¹⁵ or our data. Thus, the effect of the elevated-chair position may have prompted the participants to adopt variable release angles, thereby explaining the higher between-subjects variability.

As did earlier investigators,^{7,15} we found greater horizontal ranges for the dominant limb. Although slight discrepancies were present among the 3 studies relative to the raw differences between limbs, when expressed as the limb symmetry percentage index (dominant limb/nondominant limb × 100), our results were very similar to those in both previous studies. Limb symmetry ranged between 103% and 108% for the nonoverhead athletes included in the study of Chmielewski et al¹⁵ and between 109% and 111% for the mixed sample included in that of Negrete et al.⁷ Among our participants, limb symmetry ranged from 107% to 111% for the 3 medicine balls. The consistency of these results across the 3 studies extends the clinical relevance of using limb symmetry to evaluate performance of the seated single-arm shot put. Specifically, clinicians can expect a 3% to 11% greater horizontal range for the dominant limb in healthy participants.

Table 3. Release Angles Between the Limbs for Ball Masses

Ball Mass, kg	Release Angle, Mean ± SD		Dominant–Nondominant Difference ^a	
	Dominant	Nondominant	Mean ± SD	Participants Within ±8°, % (n)
1	49.1 ± 5.9	47.3 ± 4.4	1.8 ± 6.9	77 (23)
2	48.7 ± 6.0	46.2 ± 4.7	2.5 ± 7.0	77 (23)
3	48.4 ± 5.4	46.0 ± 4.5	2.4 ± 6.0	80 (24)

^a Values are given as degrees from the horizontal plane.

Table 4. Measured Bilateral Horizontal-Range Differences and the Computed Influence of the Bilateral Release Height and Angle Differences^a

Ball Mass, kg	Measured Bilateral Horizontal-Range Difference	Computed Influence of Release Height and Angle on Horizontal Range					
		Isolated Release-Height Differences		Isolated Release-Angle Differences		Simultaneous Release-Height and -Angle Differences	
		± Average	± Middle 75%	± Average	± Middle 75%		
1	0.54	-0.001	0.007	-0.05	-0.25	-0.26	
2	0.34	0.004	0.004	-0.06	-0.14	-0.19	
3	0.25	0.006	0.001	-0.05	-0.15	-0.23	

^a Three scenarios were considered: (1) average bilateral differences, (2) isolated influence of the upper and lower values that encompassed the middle 75% of bilateral differences, (3) simultaneous influence of both factors using the upper and lower values that encompassed the middle 75% of bilateral differences. All horizontal ranges are given in meters with negative values favoring the nondominant limb.

Before considering horizontal-range limb symmetry indices as valid indicators of upper extremity strength and power in healthy individuals, we needed to establish whether the underlying projectile mechanics of the dominant and nondominant limbs were similar. Thus, detailed inspection and discussion of our release-height and release-angle results were warranted. We did not identify any differences between the limbs for either release height or release angle. Furthermore, the additional post hoc analysis examining the isolated and simultaneous influence of the upper and lower boundaries for the middle 75% of the participants provided support for interpreting horizontal-range symmetry as reflecting upper extremity strength and power. Release angle had a more potent influence on the computed horizontal ranges than release height. Even when release height and angle were considered simultaneously for the 1-kg and 2-kg ball masses, the computed horizontal effects were approximately half of the actual measured bilateral horizontal-range differences. These results provide direct support for the use of limb symmetry indices in healthy nonoverhead athletes and patients.

We observed an overall limb difference only for release velocity. The limbs did not differ with regard to vertical- and horizontal-release velocities. For this reason, the additional post hoc analyses examining the influence of the bilateral differences in projectile mechanics on the horizontal ranges did not include the range of horizontal and vertical velocities. Moreover, release velocity can be considered to represent the impulse (product of force and time) the limb applies to the medicine ball. A stronger, more powerful limb should be able to apply more force to the ball during contact. In turn, this should give the ball greater velocity; if the other 2 projection factors (release height and angle) are similar between the limbs, as our data suggest, the ball should travel farther from the stronger and more powerful limb.

Because the optimal mass of the medicine ball for the seated single-arm shot put has yet to be determined, a focus of our study was the effects of ball mass on both horizontal range and the underlying projectile mechanics. The lack of significant interactions involving limb and ball mass for the underlying projectile mechanics suggests that the limbs responded similarly to the different ball masses. Despite the similar responses of the limbs for each of the variables, the bilateral horizontal-range difference between the limbs was greater for the 1-kg ball compared with the 3-kg ball. Although we studied nonoverhead athletes, this may be a function of slightly better coordination of the dominant

limb to contend with the higher-velocity movement associated with the lighter medicine ball. Ball mass prompted smaller release angles and anterior-release velocities, yet it had no effect on release height or vertical-release velocity. The quadratic trend in the anterior-release velocities across the ball masses suggests that the difference between the 1-kg and 2-kg balls was greater than between the 2-kg and 3-kg balls. Coupled with the measured bilateral horizontal-range differences being approximately 50% greater than the computed simultaneous influence of the bilateral release-height and -angle differences for both the 1-kg and 2-kg balls, we recommend using these 2 ball masses. Future researchers should examine the relationships of upper extremity functional muscle strength and power to the 1-kg and 2-kg horizontal ranges. Their results may yield the evidence needed to identify the ideal medicine ball mass for upper extremity functional performance testing through the seated single-arm shot-put test.

It is important to recognize that we studied only healthy individuals who did not regularly participate in overhead sport activities. Based on the adaptations that likely occur secondary to injury and unilateral overhead activities, such as tennis and baseball, whether these individuals would use similar underlying projectile mechanics in the dominant and nondominant limbs is unknown. We recommend investigating both participant groups using methods similar to those in the current study. Finally, because we could not track the balls directly with high-speed video, it is important to recognize that we did not directly measure the anterior- and vertical-release velocities. Rather, we defined the release velocities based on the peak velocities occurring within 10 frames (0.1 second) before ball release. The validity of this approach should also be the focus of future research.

CONCLUSIONS

Our results support the use of the seated single-arm shot-put test as a method for conducting bilateral upper extremity FPTs. The near-identical release heights and angles for the dominant and nondominant limbs support the interpretation of bilateral horizontal-range differences as reflecting underlying strength and power differences.

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REFERENCES

1. Drouin JM, Riemann BL. Lower extremity functional performance testing, part 1. *Athl Ther Today*. 2004;9(2):46–49.
2. Fielitz L, Coelho J, Horne T, Brechue W. Inter-rater reliability and intra-rater reliability of assessing the 2-minute push-up test. *Mil Med*. 2016;181(2):167–172.
3. Falsone SA, Gross MT, Guskiewicz KM, Schneider RA. One-arm hop test: reliability and effects of arm dominance. *J Orthop Sports Phys Ther*. 2002;32(3):98–103.
4. Goldbeck TG, Davies GJ. Test-retest reliability of the closed kinetic chain upper extremity stability test. *J Sport Rehabil*. 2000;9(1):35–45.
5. Tucci HT, Felicio LR, McQuade KJ, Bevilaqua-Grossi D, Camarini PM, Oliveira AS. Biomechanical analysis of the Closed Kinetic Chain Upper Extremity Stability test. *J Sport Rehabil*. 2017;26(1):42–50.
6. Tucci HT, Martins J, Sposito Gde C, Camarini PM, de Oliveira AS. Closed Kinetic Chain Upper Extremity Stability test (CKCUES test): a reliability study in persons with and without shoulder impingement syndrome. *BMC Musculoskelet Disord*. 2014;15:1.
7. Negrete RJ, Hanney WJ, Kolber MJ, et al. Reliability, minimal detectable change, and normative values for tests of upper extremity function and power. *J Strength Cond Res*. 2010;24(12):3318–3325.
8. Negrete RJ, Hanney WJ, Kolber MJ, Davies GJ, Riemann BL. Can upper extremity functional tests predict the softball throw for distance: a predictive validity investigation. *Int J Sports Phys Ther*. 2011;6(2):104–111.
9. Clemons JM, Campbell B, Jeansonne C. Validity and reliability of a new test of upper body power. *J Strength Cond Res*. 2010;24(6):1559–1565.
10. Harris C, Wattles AP, DeBeliso M, Sevene-Adams PG, Berning JM, Adams KJ. The seated medicine ball throw as a test of upper body power in older adults. *J Strength Cond Res*. 2011;25(8):2344–2348.
11. Stockbrugger BA, Haennel RG. Validity and reliability of a medicine ball explosive power test. *J Strength Cond Res*. 2001;15(4):431–438.
12. Limbaugh G. *Comparison of Standing Single Arm Shotput Performance Between Limbs With Different Loads in Collegiate Baseball Players* [master's thesis]. Savannah, GA: Armstrong State University, Department of Health Sciences; 2010.
13. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*. 1970;2(2):92–98.
14. Johnson WM, Murphy T, Brown D, Riemann B, Suttle J, O'Canas M. Design and evaluation of a touch activated glove system for upper extremity rehabilitation studies. Paper presented at: American Society of Mechanical Engineers 2015 International Mechanical Engineering Congress and Exhibition; November 13–19, 2015; Houston, TX. 2015(57380):V003T003A090.
15. Chmielewski TL, Martin C, Lentz TA, et al. Normalization considerations for using the unilateral seated shot put test in rehabilitation. *J Orthop Sports Phys Ther*. 2014;44(7):518–524.

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