Isokinetics and Exercise Science 23 (2015) 151–160
DOI 10.3233/IES-150575
IOS Press

Reliability and validity of medicine ball toss tests as clinical measures of core strength

Mallory A. Sell*, John P. Abt, Timothy C. Sell, Karen A. Keenan, Katelyn F. Allison,
Mita T. Lovalekar and Scott M. Lephart
Department of Sports Medicine and Nutrition, Neuromuscular Research Laboratory, School of Health and Rehabilitation Science, University of Pittsburgh, Pittsburgh, PA, USA

Received 23 September 2014
Accepted 24 February 2015

Abstract.
BACKGROUND: Core strengthening is a significant component of training programs utilized to optimize athletic performance, reduce injury, and facilitate return from injury. Reliable and valid clinical measures of core strength are necessary to determine the effectiveness of these programs.
OBJECTIVE: The purpose was to determine the reliability and validity of three medicine ball toss tests (MBTs).
METHODS: A total of 20 healthy, physically active individuals participated. Session one included isokinetic strength testing (trunk flexion/extension, and right/left rotation) and MBTs (forward, backward, and right/left rotation); session two included only the MBTs. Average peak torque during strength testing and the average distance of three MBTs in each direction were analyzed. Intraclass correlations were calculated to determine the reliability of the MBTs between sessions, while validity between MBTs and strength was assessed though Pearson correlations.
RESULTS: Significant ICCs were observed between forward, backward, and right/left rotation MBTs (ICC $=$ 0.835; ICC $=$ 0.835; ICC $=$ 0.870; ICC $=$ 0.909; $p < 0.001$, respectively). No significant correlations were observed between the MBTs and corresponding measures of strength.
CONCLUSION: Results illustrate that MBTs have excellent reliability but are not related to isokinetic strength as measured by average peak torque. This lack of relationship may be due to differences in muscles examined, contraction type, and/or motion performed.

Keywords: Strength and conditioning, injury prevention, performance optimization, abdominal strength, core strength

1. Introduction

Core strength and stability training have become a significant component of physical fitness, rehabilitation, and performance training of athletes [1]. Core stability is defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities [8]. Core stability is an integral part of athletic performance, but a true measure of core stability is difficult to achieve. There is an inherent difficulty in measuring core stability because core stability is an all-encompassing term with the inclusion of core strength, endurance, flexibility, and neuromuscular control; therefore many individuals measure the components of core stability as opposed to core stability as a whole. A battery of tests is likely necessary to measure core stability as a combination of its individual components. This battery of tests is of particu-

*Corresponding author: Mallory A. Sell, Sports Medicine and Nutrition Department, Neuromuscular Research Laboratory, School of Health and Rehabilitation Science, University of Pittsburgh, 3830 South Water Street, Pittsburgh, PA 15203, USA. Tel.: +1 412 246 0460; Fax: +1 412 246 0461; E-mail: mas429@pitt.edu.

ISSN 0959-3020/15/$35.00

lar importance because of its implications for prediction of injury and performance. Neuromuscular control is one of the components of core stability, which has been demonstrated to be a predictor of knee injury if significant decreases are noted [16]. Although extremely important in injury reduction, neuromuscular control is inherently difficult to measure and has its limitations, specifically in measurement, in the clinical setting [16].

Of the previously mentioned core stability components, core strength may be the most important and likely the easiest to measure. The core acts as the center of the kinetic chain; energy is transferred from the core to both the upper and lower extremity to allow for optimal movement patterns [1]. The more strength that is possessed in the core musculature, the more strength can be transferred to other areas of the body [1]. This energy transfer makes the strength of the core important to all dynamic tasks, and its subsequent measurement systems of the utmost importance. Measuring the strength of the core has proven easier than other components of core stability because of the constant need for this energy transfer to occur during athletic activity. One potential method to measure core strength is through the use of medicine ball toss tests (MBTs), but the reliability and validity of these measures have not been clearly established.

Previous research has investigated several MBTs as measures of core strength and/or stability [9,12]. The reliability of the MBTs has previously been established, although methods for performing these specific MBTs may affect their ability to isolate the core musculature. For example, a forward MBT performed as an abdominal crunch with the arms locked at the ears has demonstrated excellent reliability ($r = 0.95$, $p < 0.001$); however, this may have increased reliance on the hip musculature while lifting the individual's torso from the floor [3]. Similar concerns arise in examples of MBTs that incorporate the musculature of the lower extremity. The backward overhead medicine ball (BOMB) toss test, which is a test of the posterior core musculature strength, has demonstrated high reliability ($r = 0.86$, $p < 0.01$) [9]. However, since this test is completed utilizing a standing position with a squat prior to the release of the medicine ball, as well as use of the arms, the isolation of the core musculature may be compromised. One rotational MBT has been described previously as a dynamic lateral throw, a test of the external and internal oblique muscular strength [13]. Although the methods describe maintaining a seated position on the floor with a recline to a 45 degree angle, bent knees, and fully extended arms to promote isolation of the core musculature, the difficulty of the test may lead to compromised isolation of the core musculature. This MBT has demonstrated a significant positive correlation with a counter movement vertical jump test, which is a test that has been previously described as a test of core strength (right: $r = 0.40$, $p < 0.05$; left: $r = 0.48$, $p < 0.05$) [13].

Validity of these previously mentioned MBTs has been constructed based on tests of over all power and strength. The forward MBT has been described as a test of explosive power, as measured by the standing broad jump and the vertical jump test, which predicts the strength of the anterior core musculature [12]. The test is performed from a tall kneel position, removing the lower extremities contribution to the throw, but the medicine ball is thrown in a chest pass fashion, allowing for excessive use of the arms [12]. This forward MBT, has demonstrated a significant negative correlation with a double leg lowering test, which is typically utilized as a test of core stability ($r = -0.389$, $p = 0.023$) [12]. Although the MBTs have been validated, the forward MBT and BOMB are not specific measures of the strength of the core. Without this established validity against test that can isolate the core musculature, the extent to which the MBTs predict core strength cannot actually be established.

Currently, there are very few clinic-friendly measures that are reliable and valid tests of core strength. The primary purpose of this study was to determine whether the three separate MBTs demonstrate test-retest reliability. It was hypothesized that each of the MBTs (forward, backward, and rotational) would demonstrate strong intersession test-retest reliability. The secondary purpose of this study was to determine whether the three separate MBTs (forward, backward, and bilateral rotation) can provide a valid clinical measurement tool of core strength. Each of the MBTs was compared to its respective isokinetic dynamometry strength test. It was hypothesized that each of the MBTs (forward, backward, and rotational) would demonstrate strong concurrent criterion validity compared to a test of isokinetic strength in the same direction. Determining reliability and validity of the MBTs as a clinical measure may provide clinicians and researchers with effective tools to identify weakness within the core musculature as well as to assess the relationship between core strength, injury, and impaired athletic performance.

2. Methods

A descriptive study design was utilized to assess the reliability and validity of three newly developed MBTs in the forward, backward, and right/left rotation directions. Previous literature has utilized similar MBTs as a measure of core strength, but these MBTs have demonstrated an excessive use of both the upper and lower extremity, potentially confounding the isolation of the core musculature and negatively affecting the validity of the tests. It was decided to develop new MBTs in order to better isolate the core musculature and replicate the trunk movements utilized for tests of isokinetic strength.

2.1. Subjects

Ten healthy females and ten healthy males (age: 22.7 ± 4.8 years, height: 164.8 ± 25.7 cm, weight: 71.0 ± 12.3 kg) were recruited for this study. Eight female subjects participated in Division I college gymnastics while two female and 10 male subjects participated in recreational physical activity at least three days a week. Inclusion criteria were 18–40 years old, participating in physical activity at least three days per week (30–60 minutes per day), the ability to throw a three-kilogram medicine ball without pain, and the ability to tall kneel for five minutes. Exclusion criteria were: a history of chronic back pain, defined as pain that limited sport participation and/or activities of daily living for more than one year, in the thoracic, lumbar, and/or sacral region; complaint of pain in the thoracic, lumbar, and/or sacral region at time of enrollment; or a history of back surgery in the thoracic, lumbar, and/or sacral region. Institutional Review Board approval was obtained prior to the initiation of this study. Prior to any testing procedures, each subject provided written informed consent in accordance with the University's Institutional Review Board protocol.

2.2. Procedures

Data were collected in two separate sessions over a seven-day time period, with sessions separated by at least 24 hours. During test session one subjects performed concentric-concentric isokinetic strength testing for torso flexion/extension and bilateral rotation at 60 degrees per second for five repetitions. Following isokinetic strength testing subjects performed five MBTs in the forward, backward, and right/left rotation directions. During test session two subjects performed five MBTs in the forward, backward, and right/left rotation direction. The order of the MBTs was systematically randomized using a Latin square design so that each of the six potential orders of throws were equally utilized [10]. Each subject performed the throws in the same order during both test sessions.

The Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc, Shirley, NY) was used to assess trunk flexion, extension, and bilateral rotation strength. Trunk flexion/extension and right/left rotation were tested in two separate tests. All isokinetic strength testing was performed at 60 degrees per second using a concentric/concentric reciprocal protocol [6]. For each of the tests, the individual was verbally cued as to how to move throughout the entire range of motion during the trials. For familiarization, each individual was given a practice period of three trials at fifty percent of self-perceived maximum effort followed by three trials at one hundred percent of self-perceived maximum effort. Following a one-minute rest period, each subject performed five reciprocal concentric-concentric trials at one hundred percent of the subject's self-perceived maximum effort. The average peak torque averaged across five trials for each motion was used for statistical analysis.

Trunk flexion and extension strength were assessed in the semi-standing position using the Biodex trunk flexion/extension attachment. All positioning and stabilization occurred according to manufacturer's recommendations. The axis of rotation was aligned with the superior edge of the iliac crest, while the foot plate was adjusted to allow the subject's knees to be at 10–20 degrees of flexion with their posterior thighs supported by the seat of the attachment. Two Velcro straps across the subject's thighs and two Velcro straps that crossed the subject's torso were used for stabilization allowing for optimal trunk strength production. All range of motion limits were set based on subject's individual trunk range of motion. Trunk flexion and extension isokinetic strength has been previously established as reliable with similar methods and instrumentation with an ICC of 0.74–0.98 [4]. These methods have also demonstrated validity when compared to measures of EMG of the core musculature [7].

Trunk bilateral rotation strength was assessed using the Biodex trunk bilateral rotation attachment in a seated position. All positioning and stabilization occurred according to manufacturer's recommendations. The rotation attachment was lowered to meet the subject's upper chest and secured with a Velcro strap reaching around the subject's upper back. The axis of

A B C

Fig. 1. Forward Medicine Ball Toss Test; A. Tall kneeling start position; B. Hip and lumbar extension prior to initiating throw; C. Forceful abdominal contraction with follow through after release.

rotation was aligned directly over the subjects head with hip pads adjusted to maintain the axis of rotation in an upright position. Thigh pads were placed in contact the subject's medial thighs allowing for additional stabilization and optimal trunk strength production. All range of motion limits were set based on the subject's individual trunk range of motion. Trunk bilateral rotation isokinetic strength has been previously established as reliable with similar methods and instrumentation with an ICC of 0.863 [10].

Both verbal and visual instructions were given for each of the three MBTs, including rotation to the right and left, prior to the practice period. The verbal instructions included how to tighten the core to elicit maximum effort from the core musculature. Subjects were given a separate practice period prior to each set of MBTs, in which they performed five medicine ball tosses for each of the three MBTs, including rotation to both the right and left. Following a five-minute mandatory rest period after the practice trials, the MBT data collection trials began. The weight of the medicine ball was standardized to 3 kg for all subjects. Any trials that were deemed a failure were recollected. A failure was defined as improper technique when performing the MBTs, the medicine ball making contact with any object excluding the floor prior to the first bounce, and/or the medicine ball diverting from the intended throwing area, which was subjectively determined by the tester.

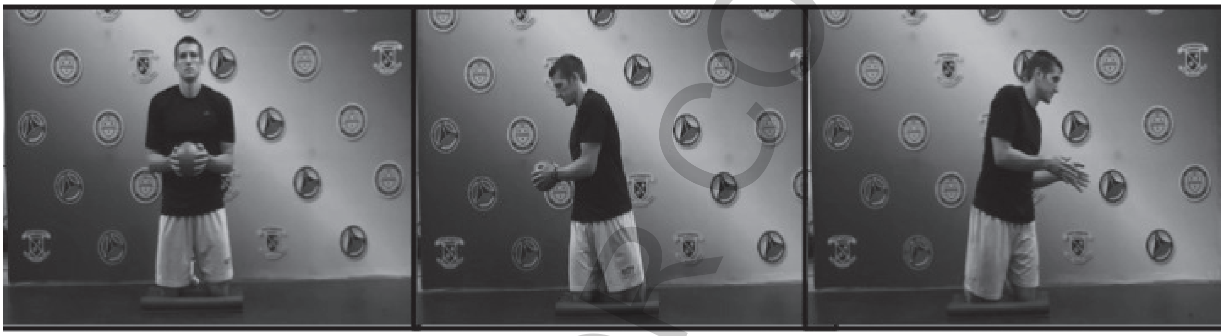
The forward MBT was a test of the anterior abdominal muscles associated with the trunk flexion strength of the core musculature. The subject assumed the tall kneeling position on the padded mat placed on the floor with the lumbar spine in a neutral position over the pelvis/hips, hips in neutral, knees flexed to 90 degrees, and the dorsal aspect of both feet and the anterior lower legs in direct contact with the mat. The most anterior aspect of the knees were placed on a tape line on the padded mat. The shoulders were flexed to 180 degrees, with the elbows locked in full extension, and wrists in neutral. The medicine ball was held in both hands with palms facing inward toward each other. The subject was instructed to maintain the position of the upper extremity, to the best of their ability, throughout the duration of the throw. To initiate the throw, the subject extended the hips and lumbar spine and then flexed the hips and lumbar spine as if to do a standard crunch. The knees, lower legs, and feet remained in the same position throughout the duration of the throw. When the lumbar spine and hips returned to a neutral position, the subject released the medicine ball with enough force to allow the ball to travel as far as possible. If necessary, the subject was allowed to fall forward, catching himself/herself with the hands. Figure 1 illustrates the forward MBT.

The backward MBT was a test of the posterior abdominal muscles associated with the trunk extension strength of the core musculature. The subject assumed an identical tall kneel start position to the forward MBT. To initiate the throw, the subject flexed the hips and lumbar spine and were allowed to drop the hips; in this position the gluteal muscles may have touched the subject's calcaneous. The subject then extended the hips and lumbar spine while maintaining the initial arm position. When the lumbar spine and hips returned to a neutral position, the subject released the medicine ball with enough force to allow the ball to travel as far as possible. Figure 2 illustrates the backward MBT.

The rotational MBT consisted of rotation to both the right and left side of the subject's body. The subject assumed a similar tall kneel start position to both the forward and backward MBT. The only positional change

A B C

Fig. 2. Backward Medicine Ball Toss Test; A. Tall kneeling start position; B. Hip and lumbar flexion prior to initiating throw; C. Forceful lumbar contraction with follow through after release.



A B C

Fig. 3. Rotational Medicine Ball Toss Test; A. Tall kneeling start position; B. Lumbar rotation prior to initiating throw; C. Forceful abdominal contraction with follow through after release.

during this test was that the arms were positioned beside the subject's torso to remain there throughout the throw, shoulders at neutral with no flexion or extension, elbows locked at 90 degrees of flexion, and wrists in neutral. The medicine ball was to be held in both hands with palms facing inward toward each other. This upper extremity position was to be maintained, to the best of the subject's ability, throughout the duration of the throw. To initiate the throw, the subject rotated the upper body at the lumbar spine (either to the right or left), and continued to maintain arm position. The subject then rotated the lumbar spine in the opposite direction as the starting position (either to the right or left). When lumbar spine returned to neutral rotation, the subject was to release the ball allowing it to travel as far as possible. The subject was able to follow through with the rotational motion of the lumbar spine. Figure 3 illustrates the rotational MBT.

The distance of each throw was measured in centimeters from the line at which the individual was tall kneeling. This line was located at the most anterior portion of the individual's body where contact was made with the padded mat, during the forward and backward MBTs. During the right/left rotational MBTs the distance of the throw was measured from the line at which the individual was tall kneeling. This line was at the most lateral portion of the individual's body where contact was made with the padded mat. The measurement was extended to the first point at which the medicine ball made contact with the floor. The measurement was made as a shot put is measured, with the tape measure placed at the zero point where the individual was tall kneeling and extended to the point at which the ball made its first contact.

2.3. Statistical analysis

All data were analyzed using SPSS 21.0 (SPSS Inc., Chicago, IL). Data was analyzed in three separate groups including, overall, females, and males. All data were assessed for normality using a Shapiro-Wilk test. Descriptive statistics were calculated for all vari-

Table 1
Medicine ball toss test descriptive statistics – overall

		Day 1		Day 2	
	n	Mean	Standard deviation	Mean	Standard deviation
Forward Medicine Ball Toss Test (cm)	20	272.48	59.06	255.34	69.14
Backward Medicine Ball Toss Test (cm)	20	287.70	71.47	267.68	77.42
Rotational Medicine Ball Toss Test-Right (cm)	20	201.83	71.64	184.82	65.09
Rotational Medicine Ball Toss Test-Left (cm)	20	187.11	56.86	174.62	59.55

Table 2
Medicine ball toss test descriptive statistics – male and female

		Day 1		Day 2	
	n	Mean	Standard deviation	Mean	Standard deviation
Male					
Forward Medicine Ball Toss Test (cm)	10	264.90	69.27	241.08	60.29
Backward Medicine Ball Toss Test (cm)	10	276.00	78.02	237.23	62.26
Rotational Medicine Ball Toss Test-Right (cm)	10	198.64	75.00	183.21	72.27
Rotational Medicine Ball Toss Test-Left (cm)	10	188.58	59.68	173.03	70.01
Female					
Forward Medicine Ball Toss Test (cm)	10	280.06	49.38	269.61	77.49
Backward Medicine Ball Toss Test (cm)	10	299.40	66.29	298.14	81.95
Rotational Medicine Ball Toss Test-Right (cm)	10	205.01	72.02	186.43	60.95
Rotational Medicine Ball Toss Test-Left (cm)	10	185.64	57.08	176.22	50.78

ables. An intraclass correlation (ICC 2,1) coeffficient, 95% confidence intervals, and the standard error of measurement (SEM; standard deviation of all averaged MBT distance*square root [1-ICC]), were used to analyze the test-retest reliability of each of the MBTs between sessions one and two. Minimal differences to be considered real were calculated using the formula MD = SEM*1.96*$\sqrt{2}$ [15]. A Pearson correlation coefficient and 95% confidence intervals were utilized to correlate each MBT with the isokinetic measures of strength in the same direction. This was determined using the distance of the MBT (session one) as it compares to the average peak torque during the Biodex testing session (session one). The significance level of alpha < 0.05 was set *a priori*.

3. Results

Tables 1 and 2 contain descriptive statistics for MBT performance. Tables 3 and 4 contain descriptive statistics for isokinetic strength test performance. All data were normally distributed; therefore Pearson correlation coefficients were calculated for all correlation analyses.

ICCs were calculated to determine the between day reliability of the forward, backward, and rotational (right/left) MBTs. Significant correlations were observed across all variables for each of the ICCs demonstrating excellent reliability for each of the MBTs [10]. ICCs are presented in Tables 5 and 6.

Pearson correlation coefficients were calculated to determine the validity of the MBTs compared to measures of isokinetic strength. No significant correlations were observed between any of the MBTs and their respective isokinetic strength test. Pearson correlation coefficients are presented in Tables 7 and 8.

4. Discussion

Core strength is an integral component of core stability and an important factor in athletic ability [1]. Measurement of true core strength in the clinical setting has proven to be a challenging task, given that current measures do not have clearly established reliability or validity. Core strength can be measured in the laboratory setting with the use of isokinetic dynamometry but this method is expensive and not portable. Previous research has suggested that MBTs may be as a proxy measure of core strength, but, although reliable, previous MBTs are of questionable validity due to accessory motions and contribution of the upper and/or lower extremity [3,9]. Therefore the purpose of this study was to determine if newly developed MBT that minimize use of the upper and lower extremity are a reliable and valid clinical measure of core strength as assessed through test-retest reliability and compared to isokinetic dynamometry, respectively.

Table 3
Isokinetic strength test descriptive statistics – overall

	n	Mean	Standard deviation	Median
Flexion Average Peak Torque (N · m)	20	179.26	57.86	157.25
Extension Average Peak Torque (N · m)	20	305.77	108.51	281.40
Right Rotation Average Peak Torque (N · m)	20	109.23	35.15	99.80
Left Rotation Average Peak Torque (N · m)	20	102.83	31.81	93.45

N·m = Newton Meter.

Table 4
Isokinetic strength test descriptive statistics – male and female

	n	Mean	Standard deviation	Median
Male				
Flexion Average Peak Torque (N · m)	10	220.21	53.10	225.00
Extension Average Peak Torque (N · m)	10	384.71	92.61	378.10
Right Rotation Average Peak Torque (N · m)	10	136.23	28.03	132.60
Left Rotation Average Peak Torque (N · m)	10	126.11	27.36	126.75
Female				
Flexion Average Peak Torque (N · m)	10	138.30	22.82	134.65
Extension Average Peak Torque (N · m)	10	226.83	49.32	224.65
Right Rotation Average Peak Torque (N · m)	10	82.22	14.22	82.30
Left Rotation Average Peak Torque (N · m)	10	79.55	13.53	79.15

N·m = Newton Meter.

Table 5
Intraclass correlation coefficients (2,1) – overall

		95% confidence interval			
	Intraclass Correlation	Lower bound	Upper bound	SEM	MD
Forward Medicine Ball Toss Test	0.835*	0.600	0.934	26.02	72.13
Backward Medicine Ball Toss Test	0.835*	0.598	0.934	30.16	83.59
Rotational Medicine Ball Toss Test-Right	0.870*	0.660	0.949	24.56	68.07
Rotational Medicine Ball Toss Test-Left	0.909*	0.742	0.966	17.44	48.34

*Significant correlation, $p < 0.001$.

Table 6
Intraclass correlation coefficients (2,1) – male and female

		95% confidence interval			
	Intraclass correlation	Lower bound	Upper bound	SEM	MD
Male					
Forward Medicine Ball Toss Test	0.877*	0.310	0.973	22.58	62.58
Backward Medicine Ball Toss Test	0.804*	−0.015	0.959	31.66	87.77
Rotational Medicine Ball Toss Test-Right	0.884*	0.616	0.969	24.56	68.08
Rotational Medicine Ball Toss Test-Left	0.898*	0.623	0.987	20.38	56.49
Female					
Forward Medicine Ball Toss Test	0.797*	0.391	0.945	28.60	79.27
Backward Medicine Ball Toss Test	0.861*	0.691	0.981	27.05	74.97
Rotational Medicine Ball Toss Test-Right	0.866*	0.530	0.965	24.03	66.59
Rotational Medicine Ball Toss Test-Left	0.936*	0.760	0.984	13.36	37.03

*Significant correlation, $p < 0.001$.

Table 7
Pearson correlation coefficients – overall

		95% confidence interval		
	r	Lower bound	Upper bound	p-value
Forward Medicine Ball Toss Test	−0.047	−0.479	0.403	0.845
Backward Medicine Ball Toss Test	−0.074	−0.500	0.380	0.756
Rotational Medicine Ball Toss Test-Right	0.051	−0.400	0.482	0.832
Rotational Medicine Ball Toss Test-Left	0.180	−0.285	0.576	0.447

Table 8
Pearson correlation coefficients – male and female

		95% confidence interval		
	r	Lower bound	Upper bound	p-value
Male				
Forward Medicine Ball Toss Test	0.008	−0.624	0.634	0.983
Backward Medicine Ball Toss Test	0.217	−0.477	0.744	0.547
Rotational Medicine Ball Toss Test-Right	0.209	−0.484	0.741	0.563
Rotational Medicine Ball Toss Test-Left	0.359	−0.349	0.806	0.309
Female				
Forward Medicine Ball Toss Test	0.288	−0.417	0.776	0.419
Backward Medicine Ball Toss Test	−0.222	−0.747	0.473	0.537
Rotational Medicine Ball Toss Test-Right	0.021	−0.616	0.642	0.954
Rotational Medicine Ball Toss Test-Left	0.034	−0.608	0.649	0.925

The specific MBTs that were employed in this study have not been described in previous literature; therefore, the reliability of these MBTs has not previously been explored. Other MBTs with similar techniques have demonstrated similar reliability to that of the MBT used in the current study. The BOMB (backward overhead medicine ball toss test) test has previously demonstrated a reliability of ICC = 0.86, while our backward MBT had just slightly reduced reliability for the overall subject group at ICC = 0.84 [9]. The reliability of both the BOMB and our backward MBT is good, but the BOMB has an increased reliance on both the upper and lower extremity to throw the medicine ball, where as our technique was able to eliminate the use of the upper and lower extremity. A forward MBT performed as an abdominal sit up in the supine position with the arms locked at the ears has been previously described as having reliability of ICC = 0.95 [3]. The forward MBT employed in the current study had just slightly reduced reliability for the overall subject group at ICC = 0.84. The reliability of both forward MBTs is good, but the difference between these tests is that our forward MBT limited hip motion by having the individual in a tall kneel position. The forward MBT employed in previous studies may have had increased reliance on the musculature surrounding the hip, using it to lift the individual's torso and upper extremity from the floor [3]. Performance of the forward MBT in this fashion may be limited by the strength of the hip flexors rather than the strength of the anterior abdominal muscles because it requires the individual to come from a supine position to an upward sitting position. The methods employed for the forward MBT in the current study may have been able to isolate the performance of the core musculature by constraining the arm and leg movements during both our forward MBT. A second possible explanation for the significant correlation was the ease and reproducibility of the MBTs. The fact that subjects were easily able to reproduce the intended movements may have led to decreased variability in MBTs both within test session one and test session two, as well as between test session one and test session two. The methods in the current study focused on the restraint of both the upper and lower extremity in order to recruit only the core musculature to perform the MBTs. While this may have negatively affected validity, it appears to have positively affected reliability by reducing the variability between trials and between subjects resulting in a significant correlation and high reliability of each of these MBTs.

The validity of the MBTs was not able to be established relative to isokinetic strength testing in the current study. This potentially limits the usefulness of the MBTs as an examination of core strength [3,9,12]. The poor validity identified in our study may be explained by the strict isolation of the core musculature during the task, which may have diverted the focus of the subject from maximal contraction of abdominal muscles during the MBTs to maintenance of the test position. This included restriction of any excessive arm movement, which may have placed too much constraint on performance of MBTs as individuals focused on restricting arm movement at the expense of maximal effort contraction of the core musculature being studied. It may also be possible that the subjects were not able to maintain the strict arm position throughout the duration of the throw. This may have resulted in small excess motion which occurred outside of the strict standardized position. This small excess motion may have subsequently positively affected performance during the MBTs. Based on observation, the tests of isokinetic strength employed in this study appear to facilitate maximal effort from the core musculature. Different contraction types may have been employed during isokinetic strength testing when compared to the MBTs. Although both the isokinetic strength testing and the MBTs are concentric movements the differentiating factor is that the MBTs are performed in an isotonic state. Isokinetic strength testing is a measure of strength at a constant velocity. Although directions, as well as visual demonstrations, were provided to each subject prior to initiation of each of the MBTs, it cannot be ensured that all of the MBTs were performed at a constant velocity. There is also the additional component of acceleration and deceleration that is inherently present during the MBTs that compromises any potential isokinetic components of the task. The variability of contraction types may have resulted in a weak correlation between the two tests. If the MBTs were done at varying velocities the measurement is no longer truly isokinetic, therefore the MBTs and tests of isokinetic strength employed by the Biodex System are no longer measuring the same type of contraction. Additionally, isokinetic strength testing is not a functional test in comparison to MBTs. This difference in functionality of the tests may have resulted in the poor correlations that were observed. But, this poor correlation does not indicate the MBTs predictive capabilities as they relate to injury or performance.

Strength measures, including MBTs and isokinetic strength, should not only be examined at the level of the overall subject group but analyzed by gender due to the inherent differences that exist. Males have demonstrated a mean and standard deviation of 247.5 ± 25.8 for trunk flexion and 267.5 ± 45.0 for trunk extension, while females have demonstrated a mean and standard deviation of 131.9 ± 54.6 for trunk flexion and 188.0 ± 84.1 for trunk extension [2,4]. During bilateral trunk rotation males have demonstrated a mean and standard deviation of 138.8 ± 33.7, while a females have demonstrated a mean and standard deviation of 94.3 ± 10.4 [5,12]. Our study demonstrated isokinetic strength measures consistent with previous research for both males and females. Our results also confirmed similar results for reliability between genders; all MBTs demonstrated good reliability.

Although both genders failed to determine validity compared to measures of isokinetic strength there were major differences between the correlation coefficients. Overall, females performed better on all MBTs, throwing the ball further than the males. Females tended to have an increased ICC compared to the males during the forward MBT. For the backward MBT males and females had similar ICCs, but males demonstrated positive ICCs while females demonstrated negative ICCs. MBTs in the direction of bilateral rotation had ICCs that were much lower for females compared to males. These differences in ICCs may be due to differences in how the gender groups approached each MBT. Females tended to have an increased ability to keep their arms locked in the appropriate positions during the duration of each throw, where males struggled to maintain proper position. But, during the rotational MBT this may have had the opposite affect, decreasing the ICC of the females. Secondly, our female population was made up primarily of division one gymnasts, the movements required for the MBTs mimic some of the movements required of their sport, specifically in the forward and backward MBT directions. This may be an appropriate explanation for the difference in direction of the ICC for the backward MBT. The females likely have increased lumbar spine extension range of motion compared to the males. During the backward MBT they were able to reach maximum extension without restrictions and excess stabilization. In opposition during the isokinetic strength testing the strict stabilization may have prevented them from reaching this same lumbar spine extension, potentially explaining the negative direction of the ICC. These differences between genders warrant further investigation to determine if gender specific MBTs are necessary to determine the validity of MBTs compared to isokinetic strength testing.

The results of the current study demonstrate that these MBTs may be used as a reliable clinical measure when comparing MBTs distances within subjects between days. However, advocating the use MBTs as a measure of core strength, specifically relative to isokinetic core strength, may be a poor decision as the MBTs demonstrated a poor relationship with isokinetic core strength in all directions tested. Future research may look to validate MBTs to other types of core strength or power in addition to revising the MBT testing procedures to potentially improve validity compared to isokinetic strength tests. The possibility exists that the speed at which the MBTs were completed was much faster than the speed at which the isokinetic strength testing was completed. It may be necessary to increase the speed of the isokinetic strength testing in order to replicate the speed that an individual produces during the MBTs. If higher speeds of isokinetic strength testing are shown to be predictive of injury or performance, then this relationship would be especially important. There is also the possibility that the strength of the core musculature is movement-specific and that the exact dynamic movement performed during the MBTs is not replicated during the tests of isokinetic strength completed with the Biodex System. Future research should look to make procedural modifications, including the speed and movement patterns during isokinetic strength testing and determine if validity is increased while reliability is preserved.

The primary purpose of this study was to determine whether the three separate MBTs could demonstrate good test-retest reliability. The secondary purpose of this study was to determine whether the three separate MBTs could provide a valid clinical measurement tool of core strength. The hypothesis that the MBTs could demonstrate strong test-retest reliability was supported by the significant ICCs that existed between the MBTs in test session one and the MBTs in test session two. The hypothesis that each of the MBTs could provide a valid clinical measurement tool of core strength was not supported, due to our lack of correlation between the MBTs and the measures of isokinetic strength. These results indicate that additional research is necessary to determine the appropriate MBTs that can be employed for assessment of core musculature strength. Future studies should include a modification of each of the MBT techniques to allow for maximal effort of the core musculature, as well as finding a field-friendly measure that is valid against isokinetic strength testing, while also being reliable.

Acknowledgement

This research was supported by the 2012 Freddie H. Fu, MD Graduate Research Award of the University of Pittsburgh.

Conflict of interest

The authors wish to declare no conflict of interest.

References

[1] Borghuis J, Hof AL, Lemmink KA. The importance of sensory-motor control in providing core stability: Implications for measurement and training. Sports Medicine. 2008; 38(11): 893-916.
[2] Cowley PM, Fitzgerald S, Sottung K, Swensen T. Age, weight, and the front abdominal power test as predictors of isokinetic trunk strength and work in young men and women. Journal of Strength and Conditioning Research. 2009; 23(3): 915-925.
[3] Cowley PM, Swensen TC. Development and reliability of two core stability field tests. Journal of strength and conditioning research/National Strength & Conditioning Association. 2008; 22(2): 619-624.
[4] Delitto A, Rose SJ, Crandell CE, Strube MJ. Reliability of isokinetic measurements of trunk muscle performance. Spine. 1991; 16(7): 800-803.
[5] Ellenbecker TS, Roetert EP. An isokinetic porfile of trunk rotation strength in elite tennis players. Medicine & Science in Sports & Exercise. 2004; 36(11): 1959-1963.
[6] Grabiner MD, Jeziorowski JJ, Divekar AD. Isokinetic measurements of trunk extension and flexion performance collected with the biodex clinical data station. The Journal of Orthopaedic and Sports Physical Therapy. 1990; 11(12): 590-598.
[7] Guilhem G, Giroux C, Couturier A, Maffiuletti NA. Validity of trunk extensor and flexor torque mesurements using isokinetic dynamometry. Journal of Electromyography and Kinesiology. 2014; 24(6): 986-993.
[8] Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Medicine. 2006; 36(3): 189-198.
[9] Mayhew JL, Bird M, Cole ML, Koch AJ, Jacques JA, Ware JS, Buford BN, Fletcher KM. Comparison of the backward overhead medicine ball throw to power production in college football players. Journal of strength and conditioning research/National Strength and Conditioning Association. 2005; 19(3): 514-518.
[10] Portney LG, Watkins MP. Foundations of clinical research: Applications to practice. 3 ed. Upper Saddle River: Prentice Hall, 2000.
[11] Sell TC, Ferris CM, Abt JP, Tsai YS, Myers JB, Fu FH, Lephart SM. The effect of direction and reaction on the neuromuscular and biomechanical characteristics of the knee during tasks that simulate the noncontact anterior cruciate ligament injury mechanism. The American Journal of Sports Medicine. 2006; 34(1): 43-54.
[12] Sell TC, Tsai YS, Smoliga JM Myers JB, Lephart SM. Strength, flexibility, and balance characteristics of highely proficient golfers. Journal of Strength and Conditioning. 2007; 21(4): 1166-1171.
[13] Sharrock C, Cropper J, Mostad J, Johnson M, Malone T. A pilot study of core stability and athletic performance: Is there a relationship? International Journal of Sports Physical Therapy. 2011; 6(2): 63-74.
[14] Shinkle J, Nesser TW, Demchak TJ, McMannus DM. Effect of core strength on the measure of power in the extremities. Journal of strength and conditioning research/National Strength & Conditioning Association. 2012; 26(2): 373-380.
[15] Weir JP. Quantifying test-retest reliability using intraclass correlation coefficient and the SEM. Journal of Strength and Conditioning Research. 2005; 19(1): 231-240.
[16] Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: A prospective biomechanical-epidemiologic study. American Journal of Sports Medicine. 2007; 35(7): 1123-1130.