Exploring the relationships among core stability, selected physical performance measures, and spiked ball velocity in male Kuwaiti volleyball players

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The primary purpose of the current study is to investigate the relationship among core stability, selected physical performance measures and spiked ball velocity. Sixteen Division I male volleyball players who were members of the Alyarmouk Sporting Club in the state of Kuwait were recruited as volunteers. Their descriptive characteristics were (mean ± SD): age = 22.66 ± 5.5 years, height = 182 ± 4.68 cm, Weight = 76.33 ± 9.75 kg, body mass Index = 22.70 ± 2.71 kg, and body fat percent = 12.15 ± 2.91%. all players underwent determination of anthropometric measurements, core stability tests, sit-ups, push-ups, and counter movement vertical jump (CMVJ) test, a double-arm medicine ball throw, a single-arm medicine ball throw, 5-m, 10-m, and 20-m sprint tests, along with spiked ball velocity (SBV) with the coach toss and spiked ball velocity (SBV) with a SPIKE IT®. The result indicated that there was a statistical significant positive relationships between SBV with the coach toss and total core (TC) (r = .77), trunk flexion (r = .55), trunk extension (r = .74), left extension (r =.58), and right extension (r = .62). The countermovement vertical jump (CMVJ) also indicated a significant positive relationship with trunk flexion (r = .47). Additionally, statistically significant and positive relationships were also identified between SBV with the coach toss and the single-arm medicine ball throw (r = .81). In conclusion: the results of this study suggest that core stability is moderately related to sport performance. Thus, coaches and personal trainers should not focus only on training the core separately and neglecting the other parts of the body. Neglecting the other body areas could lead to a muscle imbalance and possible injury.

Introduction

Core musculature is a term used to identify the muscles of the trunk and pelvis that are responsible for maintaining the stability of the spine and pelvis. Sport scientists have hypothesized that core stability is essential for the transfer of kinetic energy from the large muscles of the legs and hips to the smaller muscles of the shoulders and arms (22, 23, 17, 16). Because kinetic energy is transferred to the shoulders and arms, sport scientists and coaches reason that more force is imparted to the ball in certain sport skills, such as the baseball pitch, tennis serve, golf drive, and volleyball spike (21, 17, 16). In addition, for many strength and conditioning coaches, core stability is considered a key component in training to improve athletic performance (13, 9, 10, 22, 7, 17, 16, 20). However, the research literature has not consistently found a relationship between core stability and athletic performance.

Sharrock et al. (20) conducted a pilot study to investigate the relationship between core stability and athletic performance measures in male and female collegiate athletes. They used a total of five tests: double leg lowering (core stability test), 40-yard dash, vertical jump, T-test, and a medicine ball throw. The results suggest that there is a significant weak to moderate relationship between core stability and athletic performance, as measured by the tests.

Nesser et al.(17) examined 29 National Collegiate Athletic Association Division I male football players and used the McGill protocol (14, 13, 12) to compare core stability and athletic performance test scores. The athletic performance tests included a shuttle run, 20- and 40-yard sprints, countermovement vertical jump, one repetition maximum bench press (1RM), power clean, and squat test. Weak to moderate correlations were observed between core stability and the athletic performance measurements(r values ranging from -.36 to .60), leading Nesser and colleagues (17) to suggest that core stability plays only a minor role in the athletic performance tests assessed. The authors also suggested that core training should not be the focus of a strength and conditioning program for the purpose of increasing athletic performance.

In an effort to examine the effectiveness of core training on functional performance in college aged rowers, Tse et al. (22) assessed performance pre-and post an 8-week program. A total of 45 college age rowers were assigned to either a core training group or a control training group. Four core stability tests were used: the trunk flexor, trunk extensor, and two bilateral side bridging tests (14, 13, 12). No significant differences in the functional performance test scores (counter movement vertical jump, broad jump, 10-m shuttle run, 40-m sprint, medicine ball toss, and 2000-m rowing ergometer test) were observed between pre- and post-training. Performance on the four McGill tests improved significantly, but there were no significant changes in the pre-post comparisons for the functional performance tests, thus supporting the Nesser et al. (17) contention that core training is not a major factor for functional sport performance.

Similarly, in a more recent study, Nesser and Lee (16) investigated the relationship between core strength and performance in Division I female soccer players. The results did not indicate a high relationship between core strength and other tests of strength. Nesser and Lee (16) reiterated that since the core is only one part of the body, strength and conditioning coaches, as well as personal trainers, should not emphasize core training to the exclusion of other body parts. However, Nesser and Lee (16) acknowledge that their results could not be generalized to all sport skills. Therefore, more research is required to identify the role of core strength/stability in the execution of a variety of specific sport skills. It is possible that some sport skills rely more on core strength/stability than do other sport skills.

The volleyball spike is one of the most explosive movements in volleyball and is frequently used to end a rally and earn a point. The ability to execute a high velocity volleyball spike is an important skill for a successful volleyball offense because it decreases the ability of the defense to keep the ball in play (4, 5, 19, 2, 15). Although Hedrick (7) has suggested that the volleyball spike is a skill that depends upon core stability, little research has explored the relationship between the volleyball spike and core stability. Dynamic actions involving the core musculature could also contribute to volleyball spiking, but again, there is very little existing literature to support this contention. Therefore, the primary purpose of the present study is to investigate the relationships among core stability, selected physical performance measures, and spiked ball velocity. Spiked ball velocity (SBV) will be assessed to quantify spiking ability. It is hypothesized that strong relationships will exist among core stability, selected physical performance measures, and spiked ball velocity.

Methods

Participants

This study was approved by the Institutional Review Board (IRB) at the College of Basic Education. All participants in this investigation completed a consent form and were informed of the requirements of the study prior to participation. Sixteen Division I male volleyball players who were members of the Alyarmouk Sporting Club in the state of Kuwait were recruited as volunteers. Their descriptive characteristics were (mean ± SD): age = 22.66 ± 5.5 years, height = 182 ± 4.68 cm, Weight = 76.33 ± 9.75 kg, body mass Index = 22.70 ± 2.71 kg, and body fat percent = 12.15 ± 2.91%. Eight players were outside hitters, 3 were middle blockers, 3 were setters, and 2 were liberos. All but 2 of the 16 players were right-handed.

The principal investigator met with the players at the Alyarmouk Sporting Club to discuss their participation in the program. During this initial meeting, the participants were supplied with the principal investigator's email address and local cell phone number for further inquiries about the study. Initially, a brief description of the components of the program was provided to all potential participants. After the meeting, the principal investigator called each subject who expressed an interest in the study and explained the purposes of the study, the potential risks and benefits, and the requirements for participation. All questions were answered and the participants were informed of the time commitment involved with the study. Participants were also informed that there were no consequences if they chose not to participate in the study. Any volleyball player who chose not to participate in the study simply continued with their usual off-season training program.

Procedures

The first testing session included study familiarization followed by data collection for the anthropometric measurements, core stability tests, sit-ups, push-ups, and counter movement vertical jump (CMVJ) test. A double-arm medicine ball throw, a single-arm medicine ball throw, 5-m, 10-m, and 20-m sprint tests, along with spiked ball velocity with the coach toss and spiked ball velocity with a SPIKE IT® were completed during the second session, which took place 48 hours after the first testing session. All participants performed 10-15 minutes of warm-up activities before participating in any of the physical performance testing.

Anthropometric measurements

Each participant's height was measured barefoot with a wall mounted ruler and recorded to the nearest 0.1 cm. Participant's body weight was measured on a calibrated electric scale and recorded to the nearest 0.01kg.

Body-fat percentage (BF%) was measured using the Skinfold Caliper methodology following the procedures described by Norton et al. (18). Using a Lafayette Skinfold Caliper, the skinfold thickness was measured at seven sites: biceps, triceps, subscapular, supraspinal, abdominal, thigh, and calf on the right side of the body.

Core Stability Tests

Four bridge tests have typically been used to evaluate the stability of the core musculature: trunk flexion test, trunk extension test, and the right and left side flexion tests. The testing protocol was established by McGill (14, 13, 12) with intra class correlations of .98; .93; .95; and .94, respectively.

The trunk flexion test began with the participant in a hook-lying position, with the trunk manually supported at 60 degrees of trunk flexion. The participant's knees and hips were flexed at 90 degrees, arms crossed over chest and feet secured. After the trunk support was removed, the participant held the position as long as possible. The test was terminated when the upper body could no longer be maintained at a 60 degree angle of trunk flexion. The test score was recorded to the nearest second for each of the core stability tests. A minimum of 5 minutes recovery was allowed between each test.

The trunk extension test was performed with the participant lying prone on a treatment table with the pelvis, hips, and knees secured to the treatment table. The participant's trunk and upper extremities were supported by the seat of a chair located directly in front, and at same height as the treatment table. The chair was removed and the individual held a horizontal body position for as long as possible with arms crossed over the chest. The test was discontinued when the participant fell below the horizontal position or below the level of the examination table.

The right and left side flexion tests were performed with the participant lying on his side on an examination table. The participant was instructed to extend the knees, with the top foot placed in front of the lower foot. The individual supported his weight only on the lower elbow. The participant's hips were then raised off the table so that the body was in a straight body position on the frontal plane. The non-supporting arm was held across the chest with the hand placed on the opposite shoulder. The test was ended when the participant's starting body position could no longer be maintained. The same test was performed on both the participant's right and left sides.

Selected Physical Performance Measures

After a self-selected 10 minute warm-up period, a battery of physical performance tests were administered. The participants were instructed to give maximal effort for each of the performance tests.

Countermovement Vertical Jump Test

After placing chalk powder on his fingertips, each participant stood with feet together and the dominant side against the wall. The participant reached as high as possible with his arm and fingers extended over the head and made a chalk mark on the wall. The height of the mark was recorded to the nearest 0.1 cm. The participant was then instructed to jump from a standing position (no steps were allowed) and touch the wall at the peak height of his jump. The difference between the standing and jumping chalk marks was recorded as jump height to the nearest 1.0 cm (Adams, 2002). The participant performed three jump trials with about 30 seconds of recovery between trials. The best trial was used for data analysis (1).

Sit-up Test

The participant was instructed to lie on a mat with knees flexed and feet approximately 30 centimeters from buttocks. The principal investigator held the participant's feet on the floor and participant's arms were folded across the chest with hands on opposite shoulders. The participant raised the trunk, keeping the arms in position, curling up to touch his elbows to thighs and then lowered back to the floor so that the shoulder blades (upper back) touched the floor. The maximum number of sit-ups performed was recorded for data analysis (11).

Push-up Test

For the push-up test, a standard full-lever push-up was performed with palms flat on the floor and thumbs placed at shoulder width. The participant was instructed to keep his body straight from head to feet and to lower his body until his chin touched the principal investigator's hand, which was placed on the floor below the participant's chin. The test began in the down position, and the participant had to complete as many push-ups as possible (11).

Medicine Ball Throw Tests

Two different medicine ball throws were administered, a double-arm throw and a single-arm throw. For both tests, the distance of the throw was measured by fixing a tape measure perpendicular to a taped line that served as the start line. The landing point of the medicine ball was measured in cm and recorded as the distance of the throw.

For the double-arm throw, the participant took a stance with the shoulders parallel to the start line. With the hands positioned on the sides of the 3-kg medicine ball, the participant was instructed to quickly extend the body and hyperflex the arms at the shoulders in preparation for rapidly flexing the torso in the sagittal plane so that the ball was thrown as far as possible along the measuring tape. Only throws in which the participant did not take a step or use torso rotation were measured. The participants were allowed to practice the double-arm throw until they were comfortable with the technique (21, 22, 6).

The practice session was followed by a 20 minute recovery period (20), before the participants performed five medicine ball throws with about 30 seconds of recovery between trials. The throw distance, to the nearest cm, was recorded for all trials, but only the best trial was used for analysis.

For the single-arm throw, the participant took a stance with the body perpendicular to the start line. The 3-kg medicine ball was balanced in the palm of the dominant hand which was positioned farthest away from the start line (6). The participant was instructed to use torso rotation and an explosive overhead throwing motion to throw the medicine ball as far as possible along the tape. Taking a step during the throw was not allowed. After practicing the single-arm throw, a 20 minute recovery period was allowed before the 5 test trials were begun. The throw distance, to the nearest cm, was recorded for all trials, but only the best trial was used for analysis.

5-m, 10-m and 20-m sprints

Participants' running speed was measured with 5-m, 10-m, and 20-m sprints. The three distances were marked on the gymnasium floor. The participant assumed the starting position by lowering his center of gravity and leaning slightly forward. The participant and the principal investigator timer acknowledged their readiness by the participant yelling, " Ready," and the principal investigator yelling, "Ready" in return. The principal investigator started his stopwatch at the first starting movement of the participant, and the participant ran as fast as possible to the 5-m distance finish line. The principal investigator stopped the timer stopwatch when the participant broke the plane of the finish line. The same procedure was performed with the 10-m and 20-m distances. Each participant performed 3 maximal effort sprints of 5-m with a recovery period of 30 seconds between each trial. Each of the 3 maximal effort 10m sprints was followed by 1 minute recovery period. The 3 maximal effort 20-m sprints were followed with 2 minute recovery periods. The times for each sprint were recorded to the nearest one-hundredth of a second, but only the best sprint at each distance was used for analysis (1).

Spiked Ball Velocity (SBV)

Ball velocity was measured using a radar gun calibrated by the manufacturer to allow for small projectile tracking, reducing the validation time from 0.125 to 0.038 sec and increasing the center frequency of the tracking filters from 1,664 to 3,170 Hz (4).

SPIKE IT® Spiked ball velocity

For the **S**PIKE IT® spiked ball velocity test, each participant was instructed to adjust the ball height and position so that a stationary ball was spiked. The SPIKE IT® was used to decrease variability between spikes. Prior to testing, the participants were allowed to adjust the height of the ball in the SPIKE IT®, based on their preference; this height was recorded for consistency and measured to maintain it for all spikes. The SPIKE IT® was placed near the center of a simulated net on the same side from which the player performed the volleyball spikes. Then, a Stalker Sport2® radar gun (SRG) was positioned on a stand that was set 3 meters behind the participant, 1 meter lateral, and 3 meters high, angled so the volleyball spike would pass in front of the SRG's beam (4). Following warm-up that included specific mobility and stretching exercises of the shoulders and submaximal spiking trials, the participant was instructed to hit the volleyball with maximum force and speed using his dominant arm. Each participant was instructed to perform 5 standardized spikes (an approach followed by a vertical jump) at maximal intensity with a 1-minute rest period between trials. All the spikes were performed from position 4 and the player had to hit balls toward a delimited target zone (diagonal). Opposite directionality (position 2) was used for left-handed spikes. Only the highest spiked ball velocity (km/h) from the successive spike trials for each participant was used for data analysis.

Spiked ball velocity with the coach toss

After 20 minutes of rest, the ball velocity of a simulated volleyball spike with the coach toss was measured using the same radar gun which was calibrated to measure spike speed (4). The participants spiked a ball that was tossed by the coach. The coach was standing in the center (position 3) and was instructed to toss the ball on the same side from which the player performed the volleyball spikes. Then, a Stalker Sport2® radar gun (SRG) was positioned on a stand set 3 meters behind the participant, 1 meter lateral, and 3 meters high, angled so the volleyball spike would pass in front of the SRG's beam (4). The participant was instructed to hit the tossed volleyball with maximum force and speed using his dominant arm. Each participant was instructed to perform 5 standardized spikes (an approach followed by a vertical jump) at maximal intensity with a 1-minute rest period between trials. All spikes were performed from position 4 and players had to hit balls toward a delimited target zone (diagonal). Opposite directionality (position 2) was used for left-handed spikes. Only the highest spiked ball velocity (km/h) from the successive spike trials for each participant was used for data analysis.

Statistical Analyses

After the data were collected, statistical analyses were conducted using SPSS (Statistical Package for Social Science, Version 14.0) software. Descriptive statistics were used to identify mean, standard deviation, and range for all variables. In addition, Pearson Product Moment Correlation (r) tests were performed in order to determine correlations among core stability (trunk flexion, trunk extension, left extension, and right extension), the selected physical performance tests (5-m, 10-m, and 20-m sprints, countermovement vertical jump, medicine ball throw, push-ups, and set-ups) and SBV. The best value for each test was used for correlation analysis using the Pearson Product Moment Correlation Coefficient. To determine whether statistically significant relationships exist, the p value was set at P = 0.05 level of probability. Finally, several multiple regression analyses were conducted to determine which variable best predicted SBV with coach toss and/or the SPIKE IT®.

Results

Descriptive data for age, height, weight, body mass index (BMI), body fat percentage (BF%), standing reach height, and training experience are presented in Table 1. The mean age, and standard deviation for the entire group were (23.22 ± 2.7) with a range of 20-27. The mean height and weight and standard deviations for the entire group were 182.7 ± 4.7 cm, and 76.3 ± 9.7 kg, with a range of 177-188 cm, and 61-92 kg respectively. The mean body mass index, calculated by dividing body weight in kilograms by body height in meters squared, was 22.8 ± 2.7 with a range of 18.2-27.4 for the entire group. The mean body fat percentage and standard deviation obtained from the 7-site skinfold thickness tests for the entire group were 12.15 ± 2.9% with a range of 7.1-17.5%. The mean standing reach height, and standard deviation for the entire group were 241 ± 5.5 cm, with a range of 233-249 cm. The mean training experience and standard deviation for the entire group were 8.7 ± 2.7 yrs, with a range of 5-12 yrs.

Table 1

Descriptive Data and Anthropometric Characteristics for Division I Alyarmouk Volleyball Players

Variable	**Mean ± SD**	Range
Age	23.22 ± 2.7	20 - 27
Height (cm)	182.7 ± 4.7	177 - 188
Weight (kg)	76.3 ± 9.7	61 - 92
Body Mass Index BMI (kg/m²)	22.8 ± 2.7	18.2 - 27.4
Body Fat percentage (BF %)	12.15 ± 2.9	7.1 - 17.5
Standing Reach Height (cm)	241 ± 5.5	233 - 249
Experience (yrs)	8.7 ± 2.7	5 - 12

Note. Gender: male, n = 16

Descriptive data for trunk flexion, trunk extension, right flexion, left flexion, and total core (TC) are presented in Table 2. The mean trunk flexion, and standard deviation for the entire group were 74.1 ± 10.0 sec, with a range of 55 – 89 sec. The mean trunk extension and standard deviation for the entire group were 79.9 ± 20.5 sec, with a range of 57 – 112 sec. The mean right flexion, and left flexion, and standard deviations for the entire group were 69.7 ± 7.3 sec, 63.8 ± 12.9 sec, with a range of 54 – 77 sec, 47 – 86 sec, respectively. The mean total core (TC), and standard deviation for the entire group were 289.7 ± 34.5 sec, with a range of 221 – 315 sec.

Table 2 Descriptive Data for Core Stability Tests for Division I Alyarmouk Volleyball Players

Variable	Mean ± SD	Range
Trunk Flexion (sec)	74.1 ± 10.0	55 - 89
Trunk Extension (sec)	79.9 ± 20.5	57 - 112
Right Flexion (sec)	69.7 ± 7.3	54 - 77
Left Flexion (sec)	63.8 ± 12.9	47 - 86
Total Core TC (sec)	289.7 ± 34.5	221 - 315

Note. Gender: male, n = 16

Descriptive data for physical performance characteristics for the entire group are presented in Table 3. The mean SBV using SPIKE IT®, and standard deviation for the entire group were18.78 ± 2.13 m-s, with a range of 15.28 – 21.39 m-s. The mean SBV with coach toss, and standard deviation for the entire group were 22.1 ± 2.1 m-s, with a range of 18.8 – 25 m-s. The mean countermovement vertical jump (CMVJ), and standard deviation for the entire group were 49.8 ± 6.3 cm, with a range of 35.8 – 58.7 cm. The mean 5-m sprint, and standard deviation for the entire group were 1.38 ± 0.2 sec, with a range of 1.16 – 1.8 sec. The mean 10-m sprint, and standard deviation for the entire group were 2.04 ± 0.2 sec, with a range of 1.75 – 2.31 sec. The mean 20-m sprint, and standard deviation for the entire group were 3.37 ± 0.2 sec, with a range of 3 – 3.66 sec. The mean push-ups, and standard deviation for the entire group were 29.1 ± 9.4, with a range of 18 – 43. The mean sit-ups, and standard deviation for the entire group were 22.7 ± 3.4, with a range of 19 – 28.The mean double-arm medicine ball throw, and standard deviation for the entire group were 8.7 ± 0.8 m, with a range of 7.6 – 10.7 m. The mean single-arm medicine ball throw, and standard deviation for the entire group were 7.8 ± 0.9 m, with a range of 6.6 – 9.9 m.

Table 3 Descriptive Data for Selected Physical Performance Measures for Division I Alyarmouk Volleyball Players

Variable	Mean ± SD	Range
SBV using SPIKE IT® (m-s)	18.78 ± 2.13	15.28 – 21.39
SBV with coach toss (m-s)	22.1 ± 2.1	18.8 – 25
Countermovement Vertical Jump (CMVJ) (cm)	49.8 ± 6.3	35.8 – 58.7
5-m Sprint (sec)	1.38 ± 0.2	1.16 – 1.8
10-m Sprint (sec)	2.04 ± 0.2	1.75 – 2.31
20-m Sprint (sec)	3.37 ± 0.2	3 – 3.66
Push-ups	29.1 ± 9.4	18 – 43
Sit-ups	22.7 ± 3.4	19 – 28
Double-arm medicine ball throw (m)	8.7 ± 0.8	7.6 – 10.7
Single-arm medicine ball throw (m)	7.8 ± 0.9	6.6 – 9.9

Note. Gender: male, n = 16

Pearson Product Moment Correlation Coefficients between anthropometric characteristics and spiked ball velocity are presented in Table 4. There are no statistically significant relationships between anthropometric characteristics and any of the core stability test scores; however; as seen in Table 4, there is a statistically significant relationship between body weight and the Spike-it® SBV (r = -.52).

Table 4

Pearson Product Moment Correlation Coefficients between Anthropometric Characteristics and Spiked Ball Velocity

Anthropometrics	SBV with Coach toss	SBV using SPIKE IT®
Age	-.08	-.34
Height	.29	.25
Weight	.12	-.52*
BMI	.04	.38-
%Fat	.30-	.13-
Standing reach	.24	.18
Experience	.22	.28

Note. *Statistically Significant (p< 0.05). Gender: male, n = 16.

The Pearson Product Moment Correlations Coefficients and level of significance for core stability tests, selected physical performance measures, and spiked ball velocity (SBV) are presented in Table 5. For the relationships between core stability tests and spiked ball velocity tests, statistically significant and positive relationships were identified between spiked ball velocity with the coach toss and total core (r = .77), trunk flexion (r = .51), trunk extension (r = .74), left flexion (r =.58), and right flexion (r = .62). For the relationships between spiked ball velocity tests, and selected physical performance measures, statistically significant and positive relationships exist between spiked ball velocity with the coach toss and the single-arm medicine ball throw (r = .81). Statistically significant and positive relationships are evident between spiked ball velocity with the coach toss and countermovement vertical jump CMVJ (r = .43), and spiked ball velocity using the Spike-it® and the countermovement vertical jump CMVJ (r = .47).

Table 5

Pearson Product Moment Correlation Coefficients (r) for Core Stability Tests, Selected Physical Performance Measures and Spiked Ball Velocity

Variables	SBV Coach Toss	SBV SPIKE IT®
Core Stability Tests		
Trunk Flexion (sec)	.51*	.28
Trunk Extension (sec)	.74*	.39
Right Flexion (sec)	.62*	.16
Left Flexion (sec)	.58*	.28
Total Core (sec)	.77*	.29
Physical Performance Measures		
Double-arm medicine ball throw (m)	.27	.23
Single-arm medicine ball throw (m)	.81*	.34
CMVJ (cm)	.43*	.47*
5-m(sec)	-.19	-.24
10-m(sec)	-.12	-.15
20-m (sec)	-.22	-.43
Push ups	.39	.22
Sit ups	.06	.07

Note.*Statistically Significant (p< 0.05). Gender: male, n = 16

Several multiple regression analyses were conducted to determine which variable best predicted SBV with coach toss and/or the spike it®. The regression analysis revealed that the single arm medicine ball throw (r = .53) is best predicts SBV only with the coach toss SBV, followed by the total core (r = .33), and CMVJ (r = .14), as seen in Table 6.

Table 6

Regression Analysis Summary for Division I Alyarmouk Volleyball Players Predicting SBV with Coach Toss

Variable	B	SEB	Beta
constant	8.012	15.405	
Single-arm medicine ball throw	4.252	1.340	.53
Total Core	.106	.047	.33
CMVJ	.49	.215	.14

Note: Gender: male, *n* = 16 *p*<.05

Discussion

The present study was designed to follow-up on the suggestion of Nesser and Lee (16), Nasser, et al (17) that future research should examine the relationship between functioning of the core musculature and a specific sport skill. The specific sport skill selected for the present study was the volleyball spike with SBV being used to quantify spiking performance. This was the first study in which SBV was assessed with both a stationary ball position and a coach tossed ball. While the primary purpose of the present study was to investigate the relationships among core stability, selected physical performance measures and SBV, the observation that significantly higher SBV occurred with the coach tossed ball compared to the SPIKE IT®SBV was an interesting finding. The mean SBV with coach toss was 22.1 which is significantly faster than the 18.78 for the SPIKE IT®SBV. In addition, as may be seen by Table 7, the coach toss SBV is closer to values previously reported for male volleyball players. The results suggest that when assessing SBV, having a coach toss the ball or set the ball will yield higher SBV.

Table 7
Comparison of Means (SD) for Spiked Ball Velocities for Male Volleyball Players.

Subjects	Authors	Competitive Level	N	SBV (m/s)
Male	Coleman et al., 1993 (3)	Senior	10	27.0±0.9
Male	Forthomme et al., 2005 (5)	international Professional – D1	11	28.02±1.66
Male	Forthomme et al., 2005 (5)	Professional – D2	8	25.11±2.30
Male	Mitchinson et al., 2013 (15)	International	24	19.4±2.4
SBV Coach Toss	Present study	Professional – D1	16	22.1± 2.1
SBV SPIKE IT®	Present study	Professional – D1	16	18.78± 2.13

Not only did the coach toss yield significantly higher SBV, but the only significant correlations observed were between coach toss SBV and some of the selected physical performance test values. Specifically, significant correlations were observed between the McGill battery scores and the coach toss SBV (r ranging from .51 to .77) as well as the single-arm medicine ball throw and the coach toss SBV (r = .81). In designing the present study, it was hypothesized that the ability to maintain a stable core as well as the ability of the core musculature to generate force would be important for executing a volleyball spike resulting in high SBV. In other words, those players how tend to have higher ball velocity during the volleyball spike with coach toss had more core stability as measured by the McGill tests

The moderately high correlations observed in the present study between core stability and SBV are equal to or higher than the correlations published for core stability and athletic performance measures (17). Concerning soccer performance measures, Nesser and Lee (16) reported that core strength was not relative to performance test scores for Division I female soccer players.

Similarly, while the double arm medicine ball throw is frequently used to assess the relationship between core stability and athletic performance (21, 22, 6), the reported correlations are weak to moderate. In the current study, both the double arm medicine ball throw and a single arm medicine ball throw were administered. Fewer researchers have used a single-arm medicine ball throw, but because rotation of the torso in the sagittal plane (3, 2) is necessary for high ball velocity volleyball spikes, a single-arm medicine ball throw was added to the physical performance test battery for the current study. The single arm medicine ball throw was used because it is more closely simulates the rotational action of the spike.

A high positive relationship is observed between the coach toss SBV and the single-arm medicine ball throw (r = .81), but the relationship between the double arm medicine ball throw and SBV is not significant. Taken together, the significant correlations between the

McGill test measures of core stability, and the single arm medicine ball throw, also support the hypothesis that core stability is important for high SBV, at least for players at the level of the male Kuwaiti Division I volleyball players in the current study.

The correlation between CMVJ and coach toss SBV is also statistically significant (r = .43). When examining factors influencing SBV, other researchers, have reported that CMVJ is a significant factor for high SBV. Hsieh, et al. (8) reported that CMVJ significantly relates to SBV (r = .49), and Ferris, et al. (4) also reported that CMVJ significantly relates to SBV (r = .58).

No significant correlations were found between the core stability, the McGill tests, and countermovement vertical jump, sit-ups, push-ups, double arm medicine ball throw, or any of the sprints in the current study. This finding is similar to those reported by Nesser, et al. (16), who investigated the relationships between the McGill battery of tests for various performance variables, including IRM bench press, IRM squat, power clean, squat jump test, countermovement vertical jump, 20 – and 40 yard sprint, and 10 yard shuttle run.

The measures of the core stability tests from the McGill protocol (14, 13, 12) used in the present study had low to moderate significant correlations when compared to each other, which is not surprising. The tests with the greatest correlation were the right and left flexion tests ($r = .658$, $p \leq .01$). The correlations from the tests of the McGill protocol in the present study were somewhat higher than those reported by Nesser et al. (17). Nesser et al. (17) only reported significant correlations for the left flexion test to the trunk flexion test ($r = .468$, $p \leq .05$) and the right flexion test ($r = .617$, $p \leq .01$). The results of the present study and Nesser et al. (17) confirmed that there were relationships among the four component tests of the McGill protocol, possibly because they all measure core stability in their targeted muscle groups.

Conclusion

The present study's results provide some evidence in support of Tse's (22) concept that specificity of testing is critical to examining the role of core stability in sport performance. First, the SBVs observed from the Spike-it® trials were significantly lower ($p < 0.01$) than the SBVs resulting from the coach toss trials. The coach toss SBV values were not only higher in velocity than the velocities observed with the Spike-it® trials, the coach toss SBV values were more similar to values reported for other male volleyball players.

In addition, the higher correlations observed between the single-arm medicine ball throw and the coach toss SBV provide a second line of evidence in support of the concept of specificity of testing. The single-arm medicine ball throw was included in the present study because the movement of the core during the single-arm medicine ball throw is thought to be more similar to the spiking action than is the movement of the core during the double-arm medicine throw. The higher correlation between the single arm medicine ball throw and the coach toss SBV, compared to the relationship between the double arm throw and the coach toss SBV, supports the concept of specificity of testing. Also, the results of the regression analysis (Table 6) Practical Suggestions and Future Research:

The findings of the present study suggest that for modestly skilled male volleyball players, the McGill tests, in combination with a single arm medicine ball throw, may be used to evaluate SBV if a radar gun for assessing SBV is not readily available. In addition, the data from this study contribute to the growing body of research on core stability and core power, and their relationships with athletic performance.

Additionally, much more research is still needed for determining the role of core muscular training on athletic performance for different sports.

provide more evidence that the single arm medicine ball throw is the most important variable in predicting SBV with the coach toss.

The relative amount of training time devoted to core training should be based upon an analysis of the specific skills required by the athlete. However, even for those sports where functioning of the core musculature is important, coaches and personal trainers should not focus only on training the core separately and neglecting the other parts of the body. Neglecting the other body areas could lead to muscle imbalance and possible injury.

Future research should also investigate changes in core muscle function and changes in sport specific skill tests (i.e., ball velocity) with core training.

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