Appendix

ROM Testing

ROM measures chosen emphasized rotation through the shoulders, trunk, and hip along with ankle dorsiflexion due to the positional extremes needed during the loading, cocking, and deceleration stages of a fluid serve motion.[14,21] All ROM measurements were assessed using a single-examiner model using 1 trial and with the same examiner testing all measurements.

Shoulder rotational ROM was performed with the subject positioned supine with the shoulder at 90 degrees of abduction in the coronal plane (towel roll placed underneath the upper arm to maintain midline orientation with trunk) and with 90 degrees of elbow flexion. The examiner did not apply scapular stabilization during measurements. Glenohumeral ER ROM was measured when a firm end feel or subject discomfort was reached. Shoulder IR ROM was measured by whichever came first: a firm end feel, subject discomfort, or the point where the posterolateral acromion was visualized to rise off the table. Goniometric measurement was made using the axis at the olecranon, the moving arm aligned with the shaft of the ulna, and the stationary arm along the vertical axis. These methods were chosen due to having a single tester and have shown fair to good intrarater reliability (ICCs, 0.58-0.73).[1,17]

Trunk rotation was measured using the seated rotation test with feet flat on the floor, hips and knees bent to 90 degrees, a ball (21-cm diameter) placed between the knees to minimize motion of the LE, upright trunk position, and a 100-cm-long and 2-cm-diameter polyvinyl chloride pip (bar) placed across the anterior shoulders with a crossed-arm grip. Goniometric measurement was made at the end of the subject's active ROM. The

goniometer was aligned parallel to the ground above the subject's head with the axis at the T1 spinous process. The stationary arm was pointed directly anterior, while the moving arm rotated to maintain a perpendicular relationship to the bar. This method was chosen because it has shown good intrarater reliability (ICC, 0.87).[12]

Hip ER and IR measurements were taken while the subject was prone using an inclinometer placed at medial shaft of tibia just proximal to the medial malleolus. The measurement was recorded at a firm end feel of ER or IR while the knee was bent to 90 degrees as the examiner stabilized the pelvis. This method was chosen because it has shown good intrarater reliability (ICC, 0.85 for ER and 0.94 for IR).[19]

Ankle dorsiflexion was measured using the weightbearing lunge technique with hands on a wall and knee in line with the second toe. The inclinometer was positioned at the anterior shaft of the tibia just distal to the tibial tubercle. The measurement was made when the subject could no longer allow their tibia to slide further anteriorly without their heel lifting off the ground. This method was chosen because it has shown good intrarater reliability (ICC, 0.96).[13]

Isometric Strength Testing

Isometric strength variables were chosen for specific target muscles used during the serve, with particular interest given to test positions for exercises commonly used in the rehabilitation setting. Isometric strength testing was performed using the microFET 2 digital handheld dynamometer (Hoggan Health Industries). The microFET 2 has a certificate of calibration and documented accuracy of up to 1%. The same examiner was utilized for all isometric strength measurements utilizing a single-examiner method.

Stabilization was provided proximally as needed. Subjects were instructed to provide a maximal effort into the direction of the handheld dynamometer as a make test was performed.

UE strength measurements were attended to first. The methods chosen have shown moderate to good intrarater reliability for UE strength testing through use of a handheld dynamometer (ICCs, 0.77-0.99).[5,8,23]

Scapular plane abduction, or scaption strength, was tested with the subject seated, arm at 90 degrees elevation, and humeral ER until the "thumbs up" position was achieved. The device was placed just proximal to the radial styloid process.

Horizontal abduction strength was tested with the subject prone, arm at a position of 90-degree abduction in the coronal plane, elbow straight, and humeral ER until the "thumbs up" position was achieved, isolating middle trapezius. The device was placed just proximal to the radial styloid process. The same procedure was also used to assess horizontal abduction strength at 135 degrees of abduction in the coronal plane, isolating the lower trapezius.

Shoulder rotational strength was tested for ER and IR with the subject prone, arm at 90 degrees abduction in the coronal plane, elbow bent to 90 degrees, and neutral radioulnar and humeral positioning so that the forearm remained in the vertical axis and thumb faced toward the body. The device was placed just proximal to the wrist joint at the dorsal side for ER and the ventral side for IR.

LE strength measurements for the hip were obtained next. The methods chosen have shown good intrarater reliability for hip strength testing through use of a handheld dynamometer (ICC, 0.89-0.92).[15]

Hip abduction strength was tested with the subject side-lying, leg positioned in line with the body, neutral femoral rotation so that the foot remained in the sagittal plane, and knee straight. The device was placed just proximal to the lateral malleolus.

Hip extension strength was tested with subject prone, neutral femoral rotation so that the lower leg remained in the vertical axis, and knee flexed to approximately 90 degrees. The device was placed just proximal to the knee joint.

Motor Control Testing

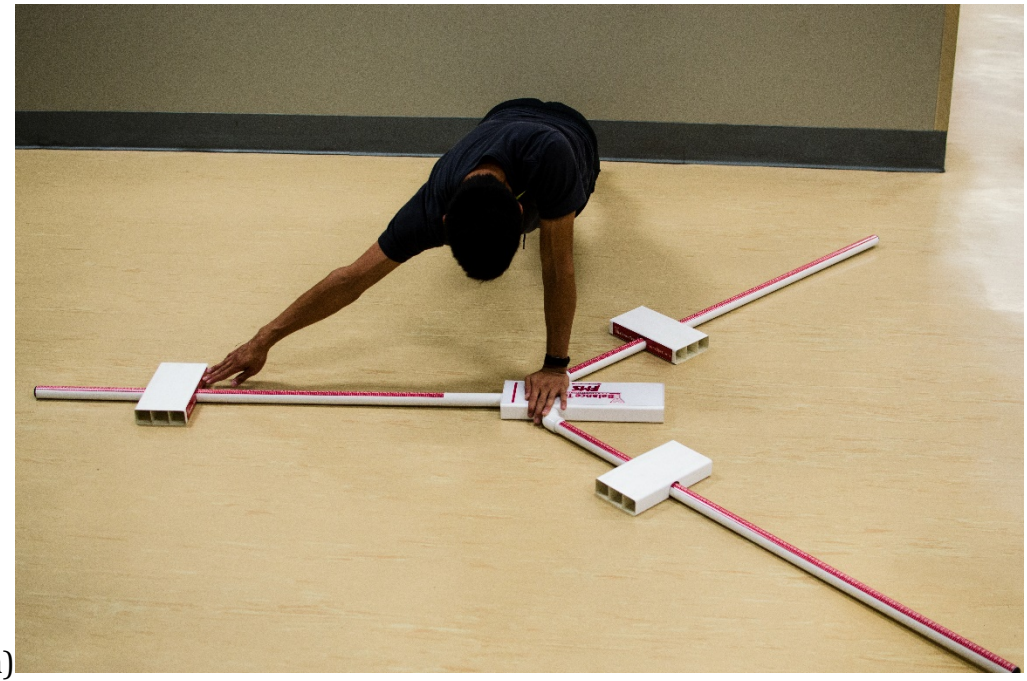
Motor control was assessed using the UE and LE Y-balance test. Positions of dynamic balance during this test involved body awareness and core control that can be related to the coordination needed in the tennis serve during the loading phase, the outstretched arm at ball impact, and the landing on the front leg during follow through. All testing was performed using the Y-Balance Test Kit (FunctionalMovement.com).

All values obtained were normalized to the subject's limb length. Arm length was measured from posterior lateral tip of the acromion to ulnar styloid while the subject was standing with arms out to 90 degrees of abduction. Leg length was measured from anterior superior iliac spine to medial malleolus while the subject was lying supine.

The UE and LE Y-balance test instructions were conducted in the same manner. Each subject was provided a demonstration of the test, instructions on the starting position, and told to perform a maximal reach that would still allow a return to the starting position. Subjects then performed 1 practice trial per side; the next successful attempt was recorded. The LE Y-balance was performed with shoes off. The UE and LE Y-balance are

demonstrated in Figures 1 and 2 with each reach direction listed. The Y-balance test has shown good intrarater reliability (ICC, 0.91 for UE and 0.88 for LE).[18,27]

(a)



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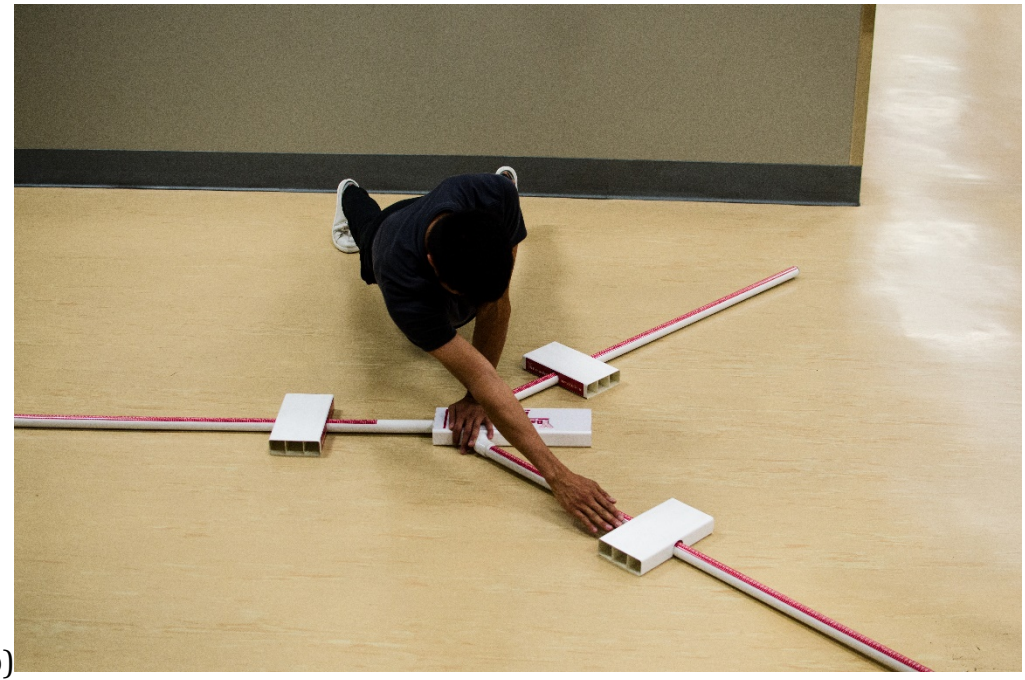


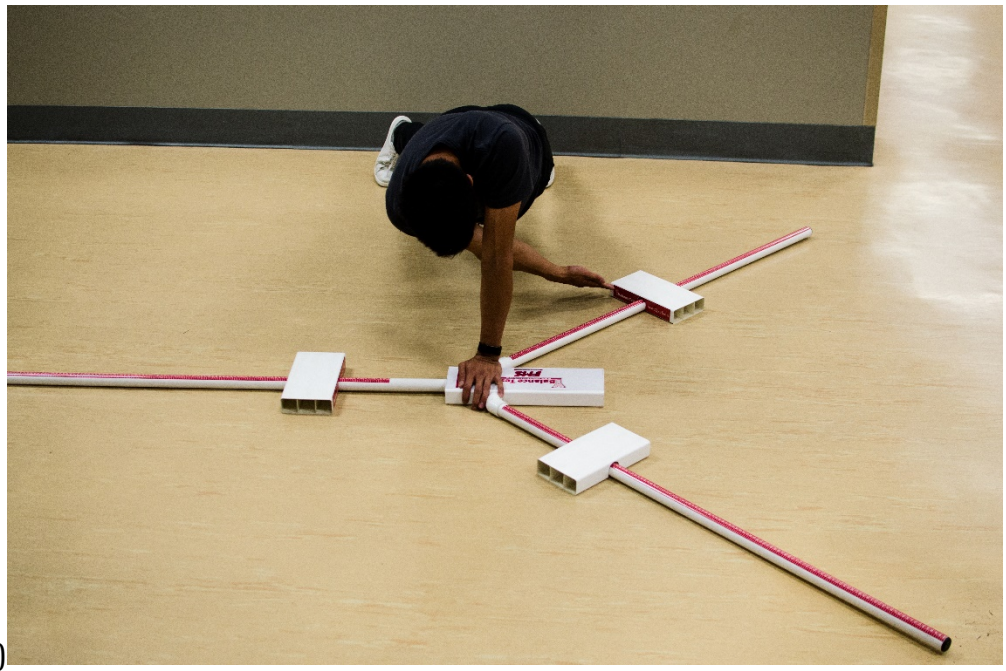
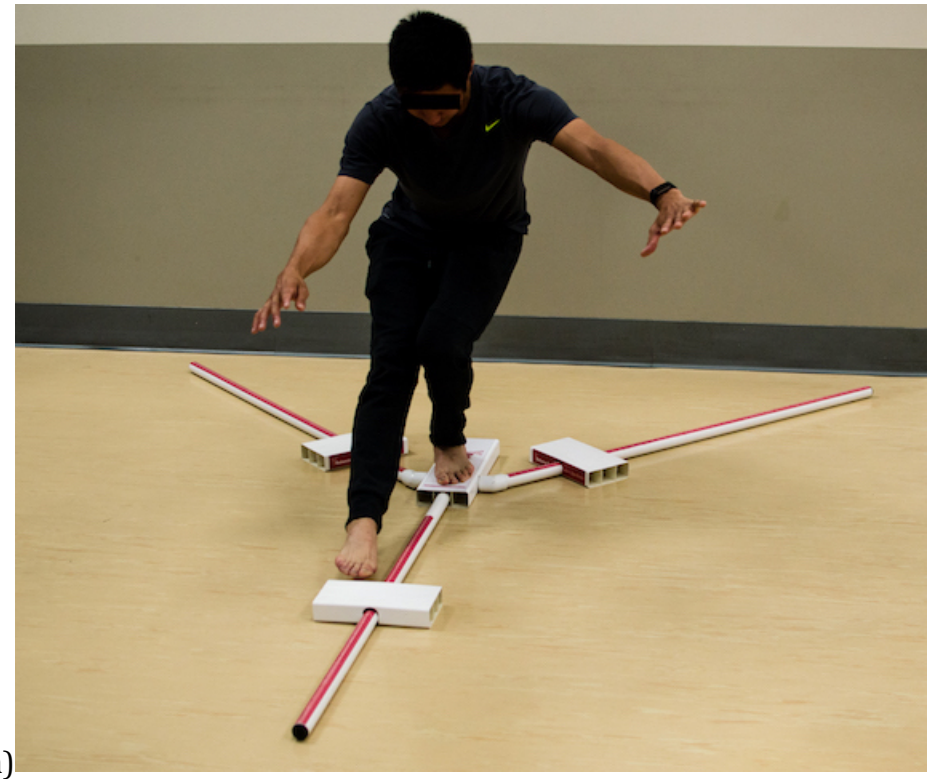
(c) 

Figure 1. Upper extremity Y-balance testing: (a) medial reach, (b) anterolateral reach, and (c) posterolateral reach.

(a) 

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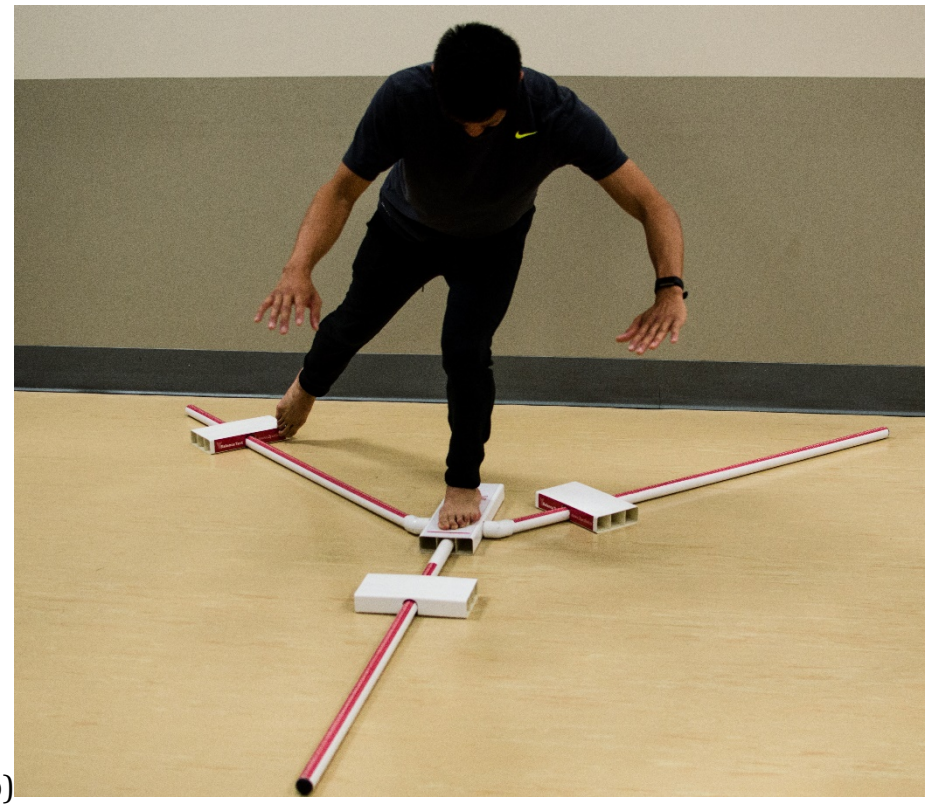

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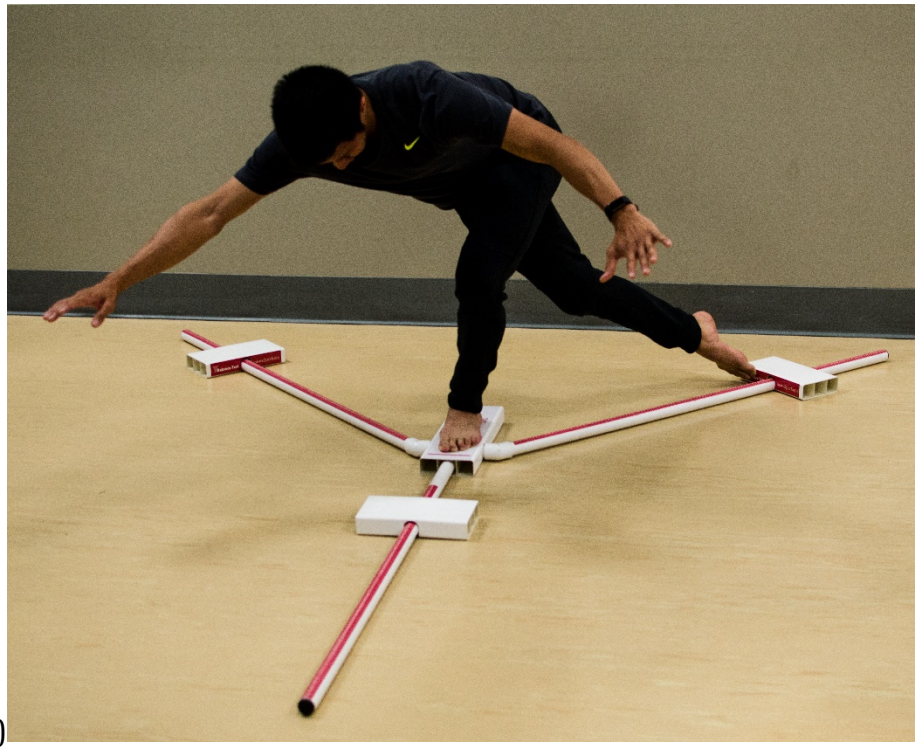

Figure 2. Lower extremity Y-balance: (a) anterior reach, (b) posteromedial reach, and (c) posterolateral reach.

Power Testing

The power variables chosen emphasized measures that would be sport-specific to the tennis serve and minimize equipment needs. Due to the similarities between the tennis serve and a throwing motion, the seated unilateral shot put test was selected to test UE power. Due to the variety of foot loading patterns and asymmetrical loading on each leg from the loading stage to follow through, a combination of a broad jump test and single-leg (SL) hop tests on each leg were included.

Seated unilateral shot put testing was performed on the subject's dominant and nondominant arm. Subjects were positioned with their back against a wall, knees bent at a right angle, feet flat on the floor, and next to a doorway as to allow unrestricted arm motion on the test side (Figure 3). Subjects held a 2.72-kg medicine ball at shoulder height and were instructed to push (not throw) the ball as far forward as possible, while keeping the rest of their body in contact with the wall. Subjects were provided a demonstration prior to the test and then 1 practice trial per side before actual trials. Subjects were then allotted 3 attempts per side, with the average maximum distance recorded. This test has shown good intrarater reliability (ICC, 0. 98). All values of this test were then normalized through allometric scaling in relation to UE limb length.[6]

Figure 3. Seated shot put throw.

LE power was tested via the double-legged broad jump and the SL hop test (performed on each leg). Shoes remained on during testing. For each test, subjects were instructed to jump as far forward as possible while being able to stick the landing. No instruction was provided as to what to do with their upper extremities. The broad jump test was performed before the SL hop tests. Subjects were provided a demonstration of the tests and 1 practice trial each before recorded trials. Subjects were then allotted 3 attempts

per side, with the average maximum distance recorded. The broad jump and SL hop test show good intrarater reliability (ICC, 0.97 and 0.85, respectively).[3,22]

Serve Speed Testing

Serve speed testing was recorded using the SR3600 Radar Gun (Sports Radar LTD). This device provides resolution within 1.6 km/h for speed ranges of 16 to 402 km/h. The radar gun was positioned approximately 4 meters behind the server at the height of ball contact and aimed at the service box across the player's body. Heavy-duty Penn Championship balls were used during serve testing while ensuring playability by each ball being used within 1 hour after opening.

Subjects were allowed the warm-up of their choice prior to serving. Subjects were instructed to perform a maximal flat first serve with the ball, landing in a grid between the center service line and middle of the service box. No serve would be counted unless it was in the designated location (deuce or left side of the court for right-handed players and advantage or right side of the court for left-handed players). After each subject performed 5 "in" serves, the highest and lowest serve speed was removed to prevent outliers, and the average of the middle 3 serve speeds was recorded.[10,25]