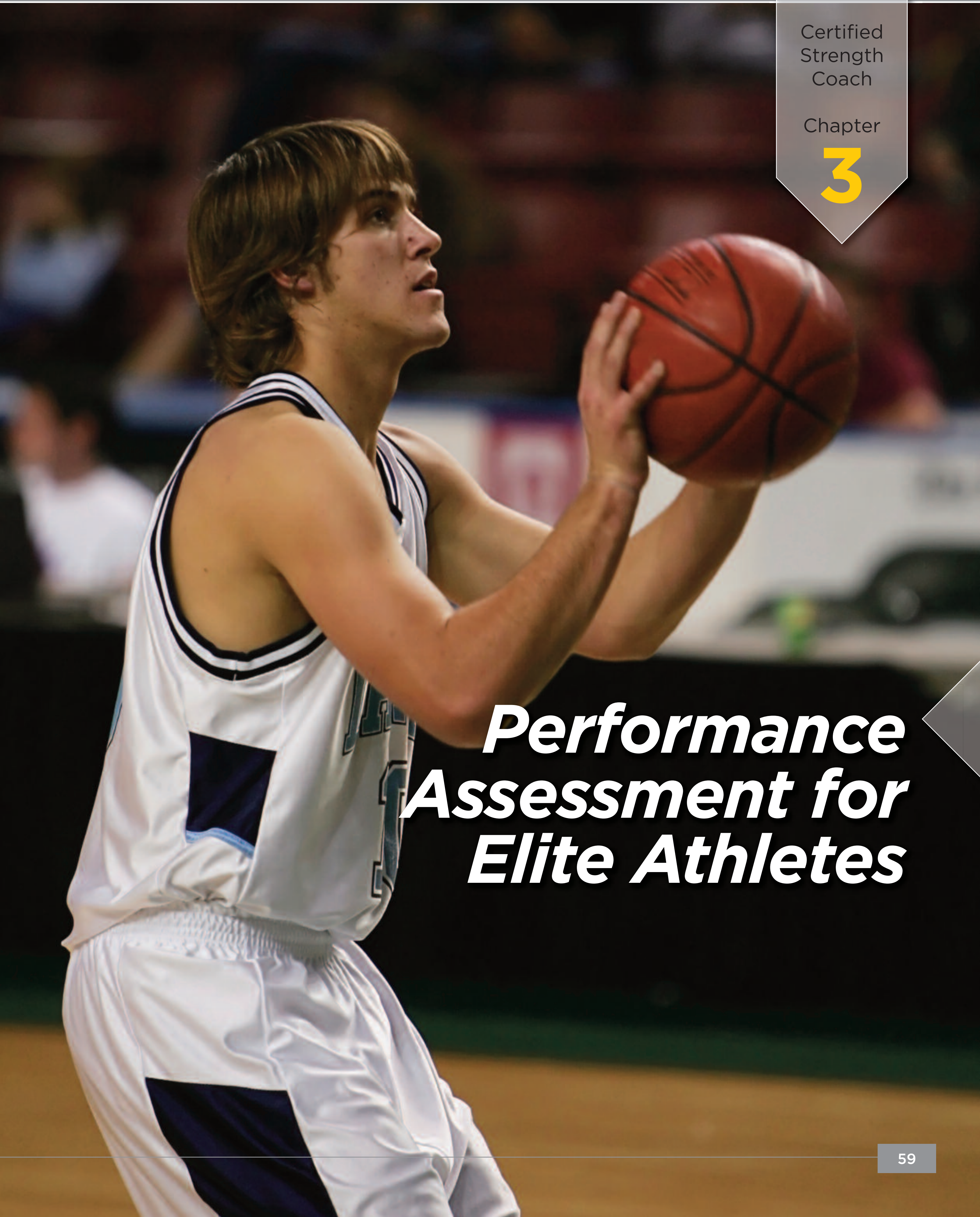
Chapter 3



Performance Assessment for Elite Athletes

Introduction to Athletic Assessment

Chapter 1 identified two categorical areas of physical fitness: health-related components of fitness (HRCF) and performance-related components of fitness (PRCF). The HRCF include cardiorespiratory fitness (aerobic efficiency), muscular fitness, flexibility, and anthropometric measurements including body composition. The PRCF include power, speed, agility (quickness), balance, and coordination. A noticeable element that separates these components is the fact that health-related factors can be independent variables, whereas the performance-related variables are co-dependent and tend to require greater neural interaction.

Due to the diverse aspects of each component of fitness and how the physical elements function within the body, no athlete can excel at all components simultaneously. For instance, an elite marathoner could not, at the same time, be an elite powerlifter as the requisite training methods and relative adaptations contradict each other neurologically, architecturally, and metabolically. Therefore, the ideal distribution of physical fitness components for an athlete is based on the sport's characteristics. For this reason, Chapter 2 provided the framework for sports dissection to identify requisite factors including movement patterns, speeds, distances covered, work intensities, work frequencies, change of direction (COD) requirements, and work:rest ratios (among others). Sport characteristics generally define success and therefore should be referenced as key metrics when testing an athlete's overall physiological aptitude. In other words, every sport has different needs in terms of relevant physical attributes that aid in optimal performance. Strength coaches should identify the predominant factors for each sport and utilize valid and applicable testing batteries to evaluate each athlete.

When deciding on tests to include in a battery for a given athlete or team, it is critical that the strength coach evaluate each intended assessment's level of **validity**, **reliability**, and objectivity. A test is considered valid when it accurately measures what it is designed to measure. Assessment protocols that have been proven valid via appropriate research methodology and match the athlete's needs should be selected whenever possible. A valid assessment can be used to compare the athlete with others at his or her level by examining normative data. A test is considered reliable when it allows for the consistent reproduction of (valid) measures in subsequent retesting scenarios. Consistency is the key to reliability and is often based on the test protocol rigors. Organization, protocol training, test calibration and many other factors can affect both validity and consistency.

DEFINITIONS

Validity –

Refers to the ability of an assessment to accurately measure what it is designed to measure

Reliability –

Refers to the ability of an assessment to allow for consistent reproduction of measures

Reproducibility is an important component of reliability, but does not assure validity. Tests can be invalid but reproducible, as in the case of the sit-and-reach test. In some instances, coaches may find themselves using a reproducible assessment that provides feedback on the training but does not have research-based validity. These concepts will be illustrated later in the chapter. Key considerations for maximizing test validity and reliability are provided in Figure 3.1.

Figure 3.1 Fundamentals of Quality Assessment – Increasing Validity and Reliability

Validity

- Ensure the test protocol is valid
- Ensure the tester is proficient in the testing protocol
- Ensure the athlete is proficient in the testing action
- Use strict discrimination during measurements
- Psychologically prepare the athlete before the test via motivational strategies
- Ensure the testing environment is safe and ideal for the assessment
- Ensure all equipment is functioning properly
- Ensure the athlete understands all pretest instructions
- Ensure no variable such as illness or significant stress will alter the data obtained
- Provide a clearly-defined scoring system

Reliability

- Duplicate testing conditions every time an assessment is implemented (i.e., time of day, environment, location, recovery status)
- Always strictly adhere to protocol requirements
- Ensure consistency in pretest factors (e.g., warm-up employed)
- Ensure consistent use of the scoring system
- Emphasize tester consistency (same coach)
- Use the same equipment

Figure 3.2 Pretest Checklists for the Athlete and Strength Coach

Athlete Checklist

- ☐ I have read or understand the testing procedures
- ☐ I am familiar with the test I will perform
- ☐ I have consumed adequate fluid
- ☐ I have acquired adequate rest the night before testing
- ☐ I have consumed a meal an appropriate duration before the test
- ☐ I have abstained from tobacco, excessive stimulants, and non-prescription drugs
- ☐ I have the proper clothing and footwear necessary for the testing activity
- ☐ I am not ill or injured

Strength Coach Checklist

- ☐ The athlete has been properly screened and has signed all applicable paperwork
- ☐ The necessary equipment is available and working properly
- ☐ All records and scoring sheets are prepared
- ☐ I understand the testing protocol
- ☐ The athlete has been instructed on testing procedures and has practiced the action to be assessed
- ☐ The testing environment has been defined and is properly prepared
- ☐ External conditions are appropriate for the test (e.g., temperature, weather)
- ☐ I have determined the test termination criteria if applicable
- ☐ Warm-up, cool down, and motivational strategy procedures are defined

Testing Rationale

Testing of any type must be purposeful. This idea has far-reaching implications that span across need, accuracy, relevance, and important resources such as time.

A test should only be used if the obtained data:

- Is valid and can be used for program development
- Can and will be duplicated with high reliability
- Predicts performance in the specific sport
- Can be properly implemented with the resources and time available
- Does not compromise any aspect of training or other assessment
- Does not increase the risk for injury

Many coaches simply test to test, without the support of scientific rationale, connection to the sport, or related score implications. For example, consider the bench press max-repetition assessment commonly used in the basketball combine. Kevin Durant is clearly one of the best players in the NBA (at the time of this text) but he could not perform a single repetition with 185 lbs in the NBA combine. So how relevant is the bench press to predictions of sport capability in basketball? Moreover, if Durant's bench press increases, does this suggest his game performance capabilities will correspondingly improve? Occasionally history dictates actions due to the simple fact that coaches assume someone down the road must have evaluated the testing protocol, or because "we have always done it."

The sit-and-reach test is another common example. Does it predict hamstring, gastrocnemius, lower back, or total body flexibility, or a combination of these measures? While the sit-and-reach is considered reliable, it is not a truly valid assessment of overall flexibility, and many factors compromise its accuracy for measuring isolated flexibility including arm:leg length ratios or hand size. In the Fitnessgram (a fitness assessment and reporting program for youth) the sit-and-reach has been modified to the back saver sit-and-reach test; allowing for a flexed knee which permits pelvic adjustments and arguably presents additional challenges to validity. There are better methods to assess flexibility; often taking more time and requiring more technical knowledge by the administrator.

In other cases test reliability is actually more useful than validity. Consider anthropometric measures of body composition. Many coaches use skinfold measurement as a quick and easy field test to monitor body fat. However, skinfold measurements are not exceptionally valid, particularly with athletes who have higher fat storage values; but they can be reliable. If validity for body composition is deemed absolutely necessary, the team should be assessed using a DEXA scan or hydrostatic weighing. A coach has to consider how important true validity is in the process of tracking a given sport performance metric. In many cases there is a way to have both. For example, during the initial assessment the team can undergo hydrostatic weighing and then be assessed using skinfold measurements. The coach can use a correlation between the two measures to identify the relationship. He or she can then use skinfold during subsequent assessments to monitor changes, and revert back to the correlation values to validate the numbers.

In other cases a test can be used by a coach for completely different purposes then attaining a valid or reliable physical measurement. Psychological aspects of work are also popular amongst both strength and sport coaches, alike. In an interview with a noteworthy coach, he was asked why his team bench presses with such frequency and his emphasis on using it as a test... his reply, "When they bench press they feel and act strong, and while our goal is power you don't feel as strong or powerful doing a vertical jump as you do pressing 315 lbs." Other coaches use tests as mental challenges and team-building efforts. Running the "gauntlet" (sequence of grueling metabolic distances), or "carting up the hill" (push a cart full of teammates up an incline drive) are very challenging, non-validated efforts that are physically applied but place the emphasis on mental effort to "never give up".

These examples suggest that although there are norms in testing there are also questions of purpose and different individual rationale for using a test. A simple criteria list can be applied to decide if a test is worth implementing from a scientific approach. Each criterion should be evidence-based, or at the very least logistic-based, when only empirical data is available to support or challenge a test selection.

Figure 3.3

Test Selection Criteria

- Level of test validity
- Level of test reliability
- Prediction or correlation of test to sport performance metrics
- Risk of injury/safety
- Qualifications of tester to perform the test
- Level of technical skill by the athlete required to perform the test
- Availability of adequate resources and equipment needs
- Time available to perform the test
- Number of athletes that can be tested at a time
- Test environment requirements

Each of the criteria in Figure 3.3 should be considered during a coach's decision to implement a given test, and when it should be employed. For instance, freshman volleyball players can safely be tested for power using the countermovement vertical jump (CMJ) test. It is valid and reliable, requires limited resources and technical skill to implement, has validated norms and has direct correlation to the sport. The 3RM power clean is another test for power, but does not qualify against the criteria as easily. New athletes on a collegiate team may or may not know how to power clean, and the technical skill required could invalidate the scoring and increase the potential for injury. While a conceptual framework exists for each sport, there are far too many relative factors to create a single battery of tests. Coaches should audit all of their tests and come up with a team battery that works in their respective environment. These metrics should be tracked, correlated to performance during the season, and consequently adjusted (if necessary) to maximize success.

Test Selection Considerations

The purpose of this chapter is not to present an exhaustive list of all existing tests used to measure HRCF and PRCF; rather it will provide thought-provoking considerations and the tools necessary to develop testing programs for each specific sport via selection of assessments that measure relevant factors.

In general, there are three primary considerations that coaches must take into account when designing a testing battery:

1) All testing should be implemented under safe conditions. A strength coach who injures an important athlete during a test will likely have a very short tenure. Therefore, the risk-to-benefit ratio must be carefully evaluated before including a particular test in the program, even if the test is commonly used for the sport. Would it be logical to test a

Heisman candidate using a 1RM squat test? ESPN cites +500 lb squats on NFL-bound quarterbacks. One might ask, "Why would a coach put 500 lbs on the back of one of the best athletes in the country – what if they got hurt?"

2) All tests should be specific to the sport, the position played by the athlete, and the current status of the athlete. Team sports with multiple positions should be dissected into relevant performance considerations when establishing testing batteries.

3) Coaches should select tests that are direct measurements or are compared to direct measurements so that a statistical relationship can be found. Even though there are numerous field tests that have been used by coaches over the years, many have not been correlated scientifically to actual validated tests. This is particularly true when looking at aerobic capacity, where many field tests exist but only a small handful have been validated using athletic populations.

Assessments for the Health-Related Components of Fitness (HRCF)

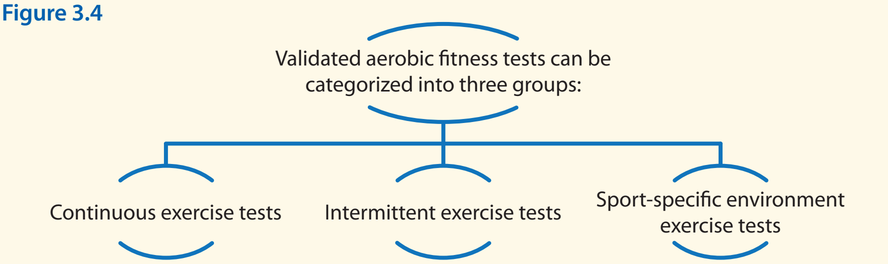
Aerobic fitness demands are very different when comparing anaerobic and aerobic sports. Certainly modality-specific VO_2 testing is important for endurance athletes (e.g., using a bike for a cyclist) but athletes involved in most anaerobic sports execute intermittent actions at varied intensities, which places high demands upon anaerobic pathways as well as the aerobic pathway. This is mainly due to the fact that the aerobic system assists PCr recovery and lowers intramuscular accumulation of glycolytic by-products such as lactate (review Chapters 6 and 16 for greater details).

Efficient aerobic support for the anaerobic systems is more important when an athlete needs to repeat high-intensity intermittent actions. Soccer is a good example because players need to repeatedly execute high-intensity sport actions with relatively short recovery periods over a 90-minute period of work. This is sometimes called repeated sprint ability (RSA) or speed strength/endurance (see chapters 11 and 16), which is closely related to both attenuation of anaerobic byproducts and the rate of recovery during PCr- and glycolytic-driven performance. Thus, despite the intermittent nature of the sport, elite Brazilian soccer field players under 17 (U17) years of age have a mean VO_2max of 56.95 ± 3.60 ml/kg/min, the under 20 (U20) years of age group has a mean capacity of 58.13 ± 3.21 ml/kg/min, and First Division players have a mean capacity of 56.58 ± 5.03 ml/kg/min [1]. This underscores the relevance of aerobic testing in most sports, regardless of the predominance of anaerobic pathways.

To directly measure VO_2max, specialized laboratory equipment including oxygen and carbon dioxide measurement devices are needed. Since most coaches do not have access to these machines, indirect measurements may be used. VO_2max is closely related to maximal cardiac output, which is in turn dependent of maximal heart rate (HRmax); allowing for reasonably accurate estimations of VO_2max from field tests.

Numerous field tests have been used over the years to assess aerobic fitness. However, coaches must be cautious and recognize the limited number that have actually been scientifically validated. Maximal effort tests should be used instead of submaximal assessments when working with athletes. This is due to the fact that even though some of the latter have been shown to correlate to actual VO_2max tests, they are usually designed for non-athletic populations. Likewise, prediction tests are in reality a prediction, which increases the risk for error. Athletes should be tested in the same manner the applicable energy system is used during competition. The problem is, if these recommendations are taken into account, the number of testing options becomes somewhat limited.

Figure 3.4



Two continuous exercise tests have been shown to have "excellent reliability" among young and healthy populations: the Leger shuttle-run test and the Cooper's 12-minute run test [2]. The Leger shuttle-run test requires the participating athletes to run back-and-forth between lines measured 20 m apart. The running speed starts at 8.5 km/h, and is increased every minute by 0.5 km/h. The speed is usually controlled by an audible "beep" which sounds each time the athlete is expected to reach each line. Each minute or speed increase is considered a "stage" and each touch of the line is considered a "shuttle". The test ends when the athlete fails to touch the line with their feet before the "beep" on two consecutive shuttles. The coach then records the number of "stages" and "shuttles" completed by the athlete. It is recommended that this test be performed in groups of four or five athletes to create a competitive environment, promote near-maximal efforts and increase the quality of gathered data. Coaches can then estimate each athlete's VO_2max using the final score and the following table [2, 3, 4].

Table 3.1 Predicted VO_2max values for the Leger Shuttle-Run Test Results

Level	Shuttle	VO_2Max	Level	Shuttle	VO_2Max	Level	Shuttle	VO_2Max	Level	Shuttle	VO_2Max
4	2	26.8	8	11	43.3	16	4	68.5	19	6	79.2
4	4	27.6	9	2	43.9	16	6	69	19	8	79.7
4	6	28.3	9	4	44.5	16	8	69.5	19	10	80.2
4	9	29.5	9	6	45.5	16	10	69.9	19	12	80.6
5	2	30.2	9	8	45.8	16	12	70.5	19	15	81.3
5	4	31	11	10	53.1	16	14	70.9	20	2	81.8
5	6	31.8	11	12	53.7	17	2	71.4	20	4	82.2
5	9	32.9	12	2	54.3	17	4	71.9	20	6	82.6
6	2	33.6	12	4	54.8	17	6	72.4	20	8	83
6	4	34.3	12	6	55.4	17	8	72.9	20	10	83.5
6	6	35	12	8	56	17	10	73.4	20	12	83.9
6	8	35.7	12	10	56.5	17	12	73.9	20	14	84.3
6	10	36.4	12	12	57.1	17	14	74.4	20	16	84.9
7	2	37.1	13	2	57.6	18	2	74.8	21	2	85.2
7	4	37.8	13	4	58.2	18	4	75.3	21	4	85.6
7	6	38.5	13	6	58.7	18	6	75.8	21	6	86.1
7	8	39.2	13	8	59.3	18	8	76.2	21	8	86.5
7	10	39.9	13	10	59.8	18	10	76.7	21	10	86.9
8	2	40.5	13	13	60.6	18	12	77.2	21	12	87.4
8	4	41.1	14	2	61.1	18	15	77.9	21	14	87.8
8	6	41.8	14	4	61.7	19	2	78.3	21	16	88.2
8	8	42.4	14	6	62.2	19	4	78.8			

The Yo-Yo IR test is similar to the Leger shuttle-run test in that the participating athletes are required to repeatedly perform 20m shuttle runs with an audible "beep" as a guide for cadence; however, the Yo-Yo IR includes an active recovery period.

The Cooper's 12-minute run test simply requires the participating athletes to run as many laps as possible on a track within 12 minutes. Timed tests that look at distance covered have a greater need for pre-test practice. Due to the fact that pacing affects the outcome, athletes should be proficient at performing the assessment in a manner consistent with test parameters. Using groups of four or five athletes encourages competition to promote high levels of effort. Coaches should alert the athletes as time elapses at 3, 6, and 9 minutes to help with proper pacing. They are also required to count the number of laps completed (each lap being 400 m) during the test time and use a measuring tape to define the number of meters (1-399) that the athlete covers after completing the last lap. Clearly, there is an added complication to validity, making attention to detail very important for this assessment. Coaches must ask the athlete to stop on the spot when the 12 minutes are up, and mark the track floor with tape just in front of the athlete's toes. This will provide the coach with a more precise total distance covered during the test [2, 5].

To estimate each athlete's VO_2max, the coach then uses Cooper's original equation [5]:

$$VO_2max = 0.0278 \times \text{distance covered in meters} - 11.3$$

Even though the above tests can be used for most sports involving running/sprinting, their continuous nature makes them far more applicable to endurance sports. Intermittent exercise tests possess greater application for anaerobic sports. There are different options for testing in this category, but among the most reliable is the Yo-Yo intermittent recovery test (Yo-Yo IR). The test is similar to the Leger shuttle-run test in that the participating athletes are required to repeatedly perform 20 m shuttle runs with an audible "beep" as a guide for cadence; however, the Yo-Yo IR includes an active recovery period.

Specifically, the Yo-Yo IR test requires athletes to run 40 m (2 × 20 m shuttles) with a 10-second active recovery period involving 10 m of jogging (2 × 5 m). The test can be conducted at two levels. The Yo-Yo IR1 requires the athlete to perform 4 (40 m) runs at 10 km/h (0–160 m), and an additional 7 runs at 13.5–14 km/h (160–440 m). After the second set of seven runs is completed, the speed increases every 8 runs by 0.5 km/h. The Yo-Yo IR Level 2 (Yo-Yo IR2) requires the athlete to start at a faster speed than the Yo-Yo IR1 (13 km/h). Consistent with the Leger shuttle-run test, the assessment ends when the athlete cannot reach 2 of the 20 m lines when the "beep" sounds. The coach records the final distance covered and this measure is used to estimate VO_2max [6].

The VO_2max for each athlete can be obtained using the following equations [7]:

$$\text{Yo-Yo IR1 test: } VO_2max = \text{IR1 distance (m)} \times 0.0084 + 36.4$$

$$\text{Yo-Yo IR2 test: } VO_2max = \text{IR2 distance (m)} \times 0.0136 + 45.3$$

When deciding between the tests, coaches must consider that the Yo-Yo IR1 primarily focuses on the athlete's ability to execute intermittent work bouts while forcing the aerobic system to work at or near maximal levels; while the Yo-Yo IR2 is better at determining an athlete's speed endurance or his/her capacity to repeat high-intensity bouts, which demonstrates adequate anaerobic system recovery [7].

The Yo-Yo test is a useful example because it not only appears to provide an accurate estimation of VO_2max, but can also be used as a normative guide to determine competition-level VO_2 requirements. Evaluations of elite athletes in various sports involving intermittent work bouts showed that the higher the level of competition, the better an athlete performs in the Yo-Yo IR tests. For example, the highest level male national team soccer players demonstrated higher scores in the Yo-Yo IR1 test (2,420 m) than other elite club players, sub-elite players and lower-level players. A very similar pattern emerges when looking at Yo-Yo IR2 results [7].

Another interesting observation is that improvements in the Yo-Yo IR tests correlate to increases in sport-specific endurance performance. For example, professional soccer players have been shown to increase the duration and total quantity of high-intensity work bouts (e.g., sprints) performed during a game as they progressively improve their Yo-Yo IR performance. Considering the importance of repeated high-intensity work capacity in overall performance, coaches will benefit from tracking players' Yo-Yo IR tests results over time [7]. This type of relationship is paramount to test battery selection based on performance implications.

Aerobic capacity tests can also be measured in sport-specific environments. These are particularly useful for sports that do not require running or sprinting. Skating and swimming are common examples. Of the few tests that appear to be valid among athletic populations in a swimming pool, the maximal multistage swim test (MSST) is likely the best choice. This assessment is essentially a pool-based version of the Leger shuttle-run test.

The MSST requires the athlete to swim a 25 m distance starting at a speed of 1 m/sec, and increase their rate by 0.05 m/sec every two minutes. Similar to other assessments, the speed is cadence-controlled by an audible "beep" sounded each time the athlete should reach the end of the pool. The test ends when the athlete fails to be within one stroke of the end line on two consecutive shuttles. A warning should be given after the first failure to reach the mark. No flip turns are allowed and the swimming style required for the test is the front crawl. The athlete's score is equal to the number of "stages" completed. This value provides the coach with the maximal aerobic swimming velocity needed to estimate VO_2max. Table 3.2 contains the results of elite swimmers for comparative norms [8].

Table 3.2 Results of Elite Swimmers during the Maximal Multistage Swim Test (MSST) [8]

Stage	Time (min)	Velocity (m/sec)	Shuttles
1	2	1.00	5
2	4	1.05	5
3	6	1.10	5
4	8	1.15	6
5	10	1.20	6
6	12	1.30	6
7	14	1.35	6
8	16	1.40	6
9	18	1.45	7
10	20	1.50	7

Calculating VO_2max is much more complicated when compared with running tests because it requires the additional measurement of an athlete's arm stroke index (ASI). The ASI is determined by calculating the number of arm strokes divided by the participating athlete's swimming velocity over a given distance. A specific initial test must be conducted to identify this value for use in the MSST. The athlete needs to swim a total of 150 m; during which the coach measures swimming velocity and number of arm strokes every 25 m (for the last 125 m). The swimming velocity measurement starts at 25 m, and is averaged for the remaining 125 m. The arm strokes for each 25 m are also separately counted and then averaged.

The ASI is calculated as follows: [8]

Arm Stroke Index (ASI): Number of arm strokes (125 m) / freely chosen swimming velocity (m/sec)

Once the ASI is known, the following equation is used to estimate VO_2max from the MSST:

$\mathbf{VO_2max}$ = 96.94 (maximal aerobic swimming velocity in m/sec) + 0.123 (ASI) - 69.23

Based on a review of the literature, a field test for hockey that has been validated with actual direct laboratory VO_2max measures does not seem to exist. If direct test measurements are not available for coaches, the running tests (e.g., Yo-Yo IR1 and Yo-Yo IR2) may be used, although there may be problems with true accuracy due to the biomechanical differences. RSA capacity though, has been successfully measured using five repeat skating sprints, consisting of one lap around the rink with 30 seconds of rest between sprints; but this protocol has not been scientifically validated at the date of this text [9].

When a valid assessment of VO_2max and relative training velocities are not available, another practical option for coaches is to determine training intensities relative to HRmax, as mentioned earlier. Percentages of HRmax can function as a guideline for determining the most applicable intensity of a particular workout based on a measured max attained during sport-specific activity. Motion analysis in Chapter 2 identified both average and peak heart rate measures. Even though an actual VO_2max measurement is not obtained, this information will help coaches have control over the intensities for program design to match the sport environment. For example, a group of athletes from the Canadian Amateur Boxing Association were found to work at about 85% of their HRmax when they sparred with an average punch rate of 35 punches/minute (three 2-minute rounds with 1-minute standing rest periods) [10]. When performing pad work, the average work intensity was equal to 83.6% of HRmax when an average of 61 punches were thrown per minute; using the same 3-round design [10]. Consistently, and under the same design, the boxers reached 86.9% of their HRmax while punching a heavy bag (~75 lbs) when throwing an average of 70 punches/minute [10]. This identifies the fact that if premeditated training matches or exceeds sport conditions, athletes can experience sport-specific conditioning improvements. Reflecting on the boxing example, it appears that a 30-40 punch/minute frequency during sparring and a 55-75 punch/minute frequency during bag or pad work reflect intensities at which aerobic, sport-specific benefits would be derived. Using a heart rate monitor to assure the rates continuously reach appropriate levels will aid in progressive management of the training.

Muscular Fitness Testing

Testing for muscular fitness usually includes measuring an individual's capacity for both muscular strength and anaerobic endurance. However, for the purposes of sport performance, the assessment of two additional factors should be considered;

(1) joint function, and (2) trunk stabilization proficiency/endurance. These factors should be prioritized because each individual muscle and joint action may vary as it relates to the inherent ability to produce and sustain force. When only one or two measures are employed to assess maximal force production, or the capacity to sustain force output, the outcomes will most likely not be applicable to other movements or muscle groups. Additionally, muscle balance ratios across the kinetic chain play a major role in joint function and injury risk, and should be considered in an athlete's evaluation. For instance, an American football player may perform very well during the back squat test but not possess adequate muscle strength balance in the knee flexors compared to the knee extensors; placing him at an increased risk for hamstring strains when sprinting. Likewise, sport-specific muscle relationships may also warrant particular consideration during the assessment process. A tennis player for instance, will need the capacity to both accelerate and decelerate the shoulder joint during a tennis serve. Explosive actions such as this require significant force relationships. For this reason, coaches should use a logical battery of strength and endurance assessments to identify physical readiness, movement speed, force proficiency, and the potential risk for injury.

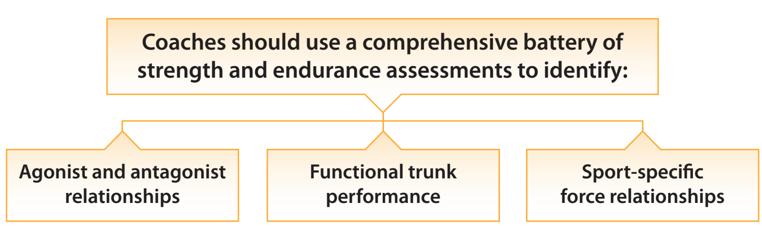
A case for the use of specific strength tests is defined during quantification of muscle balance. Figure 3.5 identifies the relationships that reduce the risk for imbalance-related injuries or performance compromises. A caveat to this is the fact that strength ratios may only define some related risk; an athlete may need more or less overall strength to remain injury-free even though the ratios seem appropriate. Coaches may decide to have a full assessment protocol to evaluate an athlete's strengths, weaknesses, and risks for potential problems; or simply assign exercises and record and compare the data collected from workouts. Key areas of attention include the quadriceps:hamstring strength ratio for running sports, internal:external rotation strength ratio for throwing and racquet sports, and trunk muscle balance for all sports.

Figure 3.5 Muscle Balance Ratio Goals

Optimal strength ratios:

- 1:1 – trunk flexors:trunk extensors
- 1:1 – hip flexors:hip extensors
- 2:3 – shoulder flexors:shoulder extensors
- 3:2 – shoulder internal rotators:external rotators
- 2:3 – knee flexors:knee extensors
- 1:1 – elbow extensors:elbow flexors
- 3:1 – ankle plantarflexors:dorsiflexors

Figure 3.6 Muscular Fitness Assessment Categories for Athletes



Muscular Strength

Traditionally, muscular fitness assessments referenced in published texts have included the use of specialized equipment such as hand grip dynamometers, cable tensiometers, and isokinetic machines to predict strength and endurance in clinical settings. Athletic populations to the contrary, use much more dynamic activities for strength assessment; and more commonly measure strength using 1RM and 3RM compound resistance exercise tests. In most athletic departments the most commonly used tests for upper and lower body strength are the bench press and back squat tests. Certainly, these tests provide a useful metric for strength in specific movements and environments, but there has been much debate concerning their overall relevance to sports. In fact, athletes might perform poorly in one or more of these assessments and still be able to excel at more sport-specific movements, or in actual competition. The example provided earlier of Kevin Durant, the NBA's 2014 MVP, failing to perform one repetition during the bench press test at the 2007 NBA combine is a clear example of this point. A second concept to the debate is the need to load athletes to maximal levels, which may increase the risk for test-related injury. Most conservative coaches prefer a 3-5RM test protocol for strength assessment, as the predictability of maximal strength is high and the risk for injury is reduced.

1RM Testing Model

The decision to test an athlete's strength using a 1RM assessment is based on three key elements:

- The need to obtain maximal strength data with absolute validity
- The athlete's proficiency in the exercise and experience handling maximal loads
- Positive evaluation of the benefit-to-risk relationship

Most coaches and athletes have experience with the bench press and back squat exercises, but proper technique is still a key factor in deciding when an athlete is qualified to perform either test. Technique qualification criteria should be used to determine which athletes can perform the test safely. When using maximal performance strength assessments, coaches should employ a testing protocol that includes preparatory lifts (specific warm-up) based on the predicted 1RM. This provides for neural readiness through progressive loading; which can improve performance and potentially reduce the risk for injury.

Figure 3.7 1RM Testing Model Protocol

Step 1: Perform a general warm-up

Step 2: Estimate the athlete's 70%, 80%, and 90% 1RM loads for the lift to be engaged

Step 3: The athlete performs 10 reps with 70% 1RM, then rests for 90 sec

Step 4: The athlete performs 5 reps with 80% of 1RM, then rests for 90 sec

Step 5: The athlete performs 3 reps with 90% of 1RM, then rests for 120 sec

Step 6: The athlete properly executes up to three (3), progressive single-repetition attempts (2-min rest periods in between) until a maximum is achieved

Multi-Rep Testing Model

The multi-rep model is based on the known relative percentages of strength associated with the performance of each repetition in a set. In general, strength consistently declines at a rate of 2-3% of the 1RM per repetition performed, up to 10 repetitions. This is due to both neural and metabolic influences. Based on these known factors, a strength assessment using multiple repetitions can be highly predictive for 1RM performance. Certainly, some athletes are more "enduring" and others are better at a single effort, but the outcomes using the multi-rep test model outline below have strong merit in programming success. The added benefits are also clear, as there is a significantly reduced risk for injury and it prevents the use of poor estimation values when attempting to predict appropriate loading during full 1RM attempts. The multi-rep model is designed for an athlete to complete between 3-5 repetitions. Stoppage of the test occurs at volitional failure represented by form compromise. Some coaches use completion of movements regardless of form as a successful lift, but this is not in line with proper test methodology or safety. As soon as the athlete compromises form, spotters should provide assistance as necessary, and the number of repetitions performed with proper technique are tallied. This way a coach can assign a weight without needing to have perfect predictive accuracy, and the athlete can perform the exercise to volitional failure in a safe manner.

Figure 3.8 Multi-Rep Testing Model Protocol

Phase 1: *Estimate the load for the multi-rep effort*

Step 1: Identify the heaviest load the athlete has recently lifted up to a 10RM
Step 2: Calculate an estimated 1RM using data from step 1
- {(.03 x repetitions performed) +1} x weight used

Step 3: Calculate the multi-rep weight (3-5RM)
- Estimated 1RM x 0.9

Phase 2: *Perform the multi-rep test and calculate 1RM*

Step 4: Perform a light warm-up for multi-rep test
Step 5: Perform as many repetitions as possible (proper form) using the weight derived from step 3
Step 6: Record repetitions and load lifted
Step 7: Enter data from step 6 into 3% formula again to calculate 1RM
- {(.03 x repetitions performed) +1} x weight used

Example: Athlete performs 8RM using 245 lbs during a workout

{(.03 x 8RM) +1} x 245 lbs = 304 lbs

304 x 0.9 = 273 lbs (adjust to Olympic weights 275 lbs)

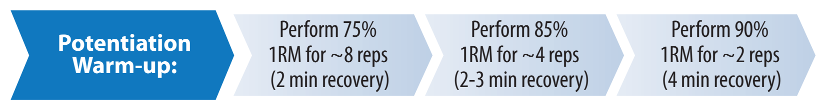
275 lbs x as many reps as possible – Athlete performs 5 repetitions during max effort test

{(.03 x 5RM) +1} x 275 lbs = 315 lbs predicted 1RM

Other tests using the multi-rep model are also commonplace, but differ in the value predicted from the outcome. Basketball and football combines use 185 lb and 225 lb bench press tests, respectively. In these tests the athlete warms-up and then performs as many repetitions as possible to failure. In the NFL some athletes attain numbers above 30 repetitions which has skewed predictability for programming, but definitely identifies they are very good at the bench press as it predicts a value >425 lbs. However, when repetitions pass the 10RM mark the predictive value is decreased for heavier loading because the lighter weight (<75% 1RM) requires much less stability across the active joints. Therefore, if an athlete performed 225 lbs for 5 repetitions (volitional failure) it would be more useful data for programming purposes than if they performed 25 repetitions (volitional failure).

A tactic that has been applied successfully for endurance tests such as the multi-rep bench press in the combine is the use of potentiation in the warm-up protocol. In this case, an athlete will warm up with more than the load to be lifted for maximal repetitions and use a 4-minute recovery period before performing the rep test. For instance, if an athlete can bench press 315 lbs and is being tested in a 185 lb multi-rep bench press (combine situation) which may have next-level implications, the warm-up should provide for optimal nervous system preparation. The warm-up would employ a similar loading sequence to the 1RM test, but a 4 minute recovery should be allowed before the multi-rep effort is performed.

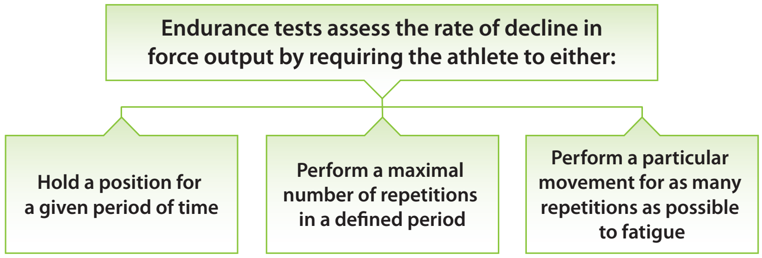
Figure 3.9 Combine Preparation Technique for the Multi-Rep Bench Press Test



In some cases the skill required to perform a test is inadequate and therefore more simplistic assessments may be necessary. As mentioned earlier, if a team is not proficient at an exercise they should not be tested using that exercise as the data will be (1) affected by technique, and (2) the risk for injury will most likely increase. If a team is not proficient at squatting, they should not be tested using the exercise even though it is one of the best choices for assessing functional lower body strength. Instead, a 5RM leg press may be used to assess general leg strength. However, the values attained cannot be used in place of others for performance correlations. Coaches must refrain from using calculated assessment outcomes in ways which they cannot be validly applied, and also decide if a test is truly necessary if requisite skill is lacking. Ultimately tests are used for data; if the data cannot be used - what is the purpose?

Muscular Endurance

Figure 3.10



Maximum Repetition Test Model

Maximum repetition tests, such as the push-up or pull-up test, can be useful for assessing upper body endurance. They can be relatively quick and easy to implement, and help clarify how well the athlete can move/control their body weight on the field. It is important to understand though, that adequate strength is required for all endurance tests. If an athlete is unable to complete ten repetitions for a given movement or test (e.g., pull-ups) they are not being assessed for endurance but rather strength; and a coach should select a different test, or modify it to their specific purpose. Modifications to a given test can be made by reducing the resistance applied during the movement; such as seen with the modified pull-up test. And although appropriate gender-specific norms for scoring may not exist, modified tests can still be useful for pre- and post-test data. Again the data must be considered relevant for the test to logically be employed. The modified pull-up test for instance provides far less data on dynamic stability and frontal plane latissimus dorsi strength than the traditional pull-up test, but it may provide better shoulder strength balance data in the transverse plane when compared with push-up test data.

Figure 3.11 Max Repetition Pull-up and Push-up Test Protocols

Pull-up test:

Step 1: The athlete grasps the pull-up bar with a pronated grip, hands approximately shoulder-width apart; the feet should not come in contact with the floor

Step 2: On cue the athlete performs as many repetitions as possible with proper form; a rep only counts if:

- The athlete's chin is drawn above the pull-up bar during the ascent phase
- The arms are fully extended during each descent phase
- The hips/trunk are not employed to assist in vertical momentum

Step 3: Upon failure or technique breakdown the coach records the total repetitions performed for comparison in subsequent assessments

Push-up test:

Step 1: The athlete starts in a push-up position with the hands placed shoulder-width apart, the thumbs directly under the shoulders and the feet no more than 6" apart

Step 2: A towel or other marker approximately 3" thick is placed under the athlete's chest

Step 3: On cue the athlete performs as many repetitions as possible with proper form; a rep only counts if:

- The athlete lowers themselves to a point where their elbows are flexed by ~90° and their chest comes in contact with the towel
- The athlete fully extends the arms during the upward phase
- The athlete does not engage in any hip extension/flexion to accelerate the movement
- The athlete does not limit the range of motion of the action through any means

Step 4: Upon failure or technique breakdown the coach records the total repetitions performed for comparison in subsequent assessments

Trunk Endurance Testing

No matter what test is used, the goal of endurance assessment is to ascertain the decline in force production of a muscle group over a defined period of time. A common problem is the concept of performance interchange between peripheral and postural muscle endurance. Using a specific test to predict total body endurance is flawed, as it assumes that postural muscle endurance reflects the capacity of other muscles, and vice versa; which is often inaccurate. Localized muscle, stabilizer, and postural muscle endurance may be interrelated, or not, depending on the activity. Therefore, each test must be recognized for the contributing factors that affect the outcome.

Coaches may want to identify the effects of postural and local joint stability before assessing peripheral muscle endurance to optimize test data. For instance, trunk muscle strength/endurance has been shown to have an impact on the performance of several athletic tasks [11] and deficiency is related to an increased risk for lumbar spine injuries [12, 13]. Additionally, trunk strength/endurance is an important component in spinal stabilization which is critical during closed-chain exercise and athletic multi-planar movements [14]. Therefore, trunk function should be initially evaluated as it may (positively or negatively) affect the athlete's capacity to perform other tasks that may be assessed during testing. Evans et al., (2007) proposed a battery of four trunk endurance tests to cover the varied planes, which may be useful in defining an athlete's predisposition for compromised performance assessment and risk for injury.

Test 1: The Biering-Sørensen trunk extensor endurance test requires the athlete to lie prone on a bench with his/her ankles locked in position. The upper trunk needs to be unsupported horizontally. The number of seconds the athlete can maintain this position is recorded with a maximum duration of 240 seconds [13]. This test is commonly performed on a glute/ham machine which slightly changes the assessment as it increases distal posterior chain contribution.

Test 2: The side bridge test requires the athlete to lie on their side with the legs/hips extended with the top foot in front of the lower foot. The free arm is placed on the opposite shoulder. The athlete must support his or her body from the forearm and feet after lifting the hips into an aligned-trunk position. The hold time is recorded and the test ends when the hips touch the floor or bench [15]. Both sides of the trunk must be assessed.

Test 3: The 60° trunk flexor endurance test requires the athlete to sit on a test bench with their knees and hips flexed at 90° while having their back supported by a board maintained at a 60° angle. The arms are folded across the chest with each hand placed on the opposite shoulder, and the feet are anchored flat on the bench. The test starts when the coach pulls the support board back 10 cm, and ends when the athlete fails to maintain their trunk in the unsupported 60° angle [15].

Test 4: The Ito trunk flexor endurance test requires the athlete to lie in a supine position and to flex their hips and knees to 90° (knee-hip/knee-ankle alignment). The athlete is then instructed to perform full-ROM abdominal flexion, and hold the position for as long as possible [16].

A group of researchers tested 79 elite athletes from six different sports and found the following results using the four-test protocol [17]:

Table 3.3 Mean Holding Times for the Isometric Trunk Endurance Tests

	All Athletes		Male Athletes		Female Athletes	
	n	Mean (S.D.) (s)	*n*	Mean (S.D.) (s)	*n*	Mean (S.D.) (s)
Biering-Sorensen	76	163.6 (50.7)	29	157.4 (42.9)	47	167.4 (55.0)
Right Side Bridge	75	104.8 (44.1)	29	126.6 (44.9)	46	91.1 (38.0)
Left Side Bridge	77	103.0 (41.3)	30	121.2 (44.4)	47	91.4 (35.0)
60° Trunk Flexion	19	223.0 (134.4)	8	224.4 (128.0)	11	222.0 (145.1)
Ito Trunk Flexion	19	148.8 (97.7)	8	162.6 (116.5)	11	138.7 (86.1)

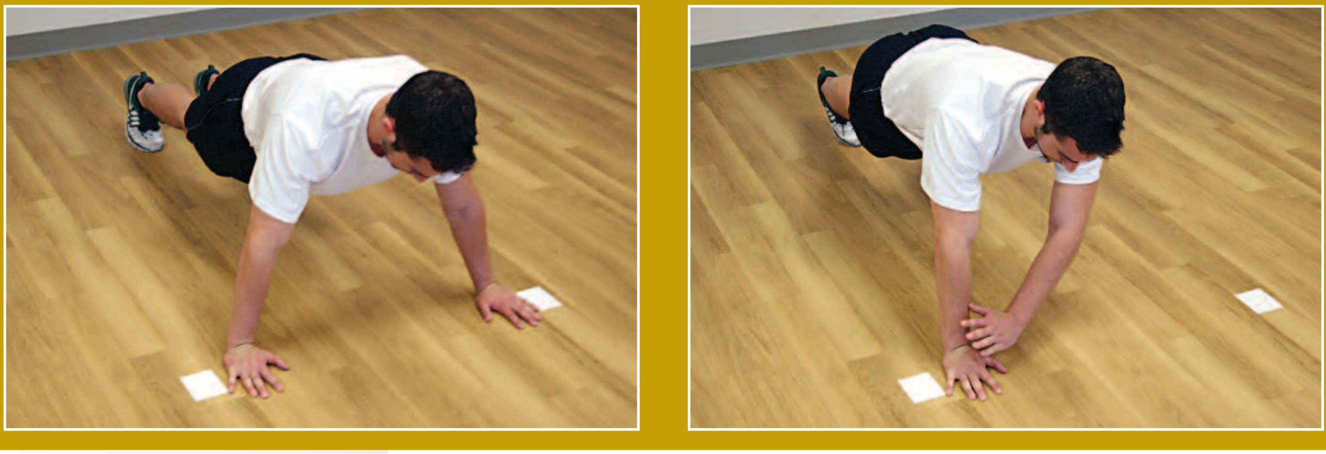
Table 3.4 Mean Side Bridge Holding Times for Male and Female Athletes in Different Sports

Sport	Gender	Right side bridge holding time (s)	Left side bridge holding time (s)	Mean side bridge (s)
Netball	Female	75.9	74.4	75.2 (6.6)
Water polo	Male	132.0	119.9	125.4 (18.5)
Hockey	Female	113.8	111.9	112.9 (10.9)
Soccer	Male	133.8	128.7	131.3 (10.8)
Soccer	Female	85.1	93.4	89.3 (8.5)
Rowing	Male	112.0	115.7	113.8 (13.2)
Rowing	Female	91.0	101.2	96.1 (11.8)
Golf	Male	108.4	109.0	108.7 (21.0)
Golf	Female	79.8	72.5	77.4 (19.2)

Certainly static tests are commonplace in clinical investigations and some have normative data which can be useful, but they should be matched to dynamic endurance assessments to identify relevant relationships of the measures. Additionally, static assessments such as the 4-test protocol proposed by Evans et al. fail to identify kinetic chain efficiency at different actions across the trunk when ground reaction force is heavily at play. The trunk is routinely subject to energy transfer and more often experiences rotational requirements during sport actions; particularly when compared to isolated flexion and extension. But again, the issue for coaches is the lack of validated assessment protocols; so there is very limited normative data around dynamic trunk proficiency. Currently, timed sit-ups and curl-ups are the most common dynamic trunk assessments used in sport environments. Push-up and pull-up tests provide some inference to the trunk's proficiency during activity, and can be used for comparative data – but their correlation to athletic activities is not overly strong. The hanging leg raise test may provide the best assessment when central and peripheral stability are compared to local muscle endurance. The test requires an athlete to hang from a bar with their arms fully extended, and perform as many repetitions with proper form as they can to volitional failure. Each repetition requires the athlete to touch their feet to the bar without swinging or flexing their arms. This assessment should only be reserved for well-trained athletes as it requires notable shoulder stability, trunk strength, and functional ROM in the latissimus dorsi, hamstrings, and lower back. The modified version of the assessment would be the hanging hip flexion test. It uses similar parameters but requires the athlete to bring the knees to a chest-height position, with a score for each time the knees reach the determined height while the arms remain fully extended.

Another dynamic assessment (usually categorized as a measure of upper extremity agility) is the Davies test. But rather than a highly-valid assessment of upper body agility, it is actually a better predictor of dynamic trunk/shoulder stability as there is no reaction stimulus. The test requires an athlete to assume an aligned, static push-up position with the feet together, hands placed on a marked surface 36 inches apart, and the arms extended. On cue they must move one hand to the other as fast as possible without raising or "excessively" translating their hips. The score is the number of contacts made in 15 seconds. The value in this test increases when it is filmed for comparative evaluation later. In many cases (like other tests) the quality of the execution is more relevant than the number scored.

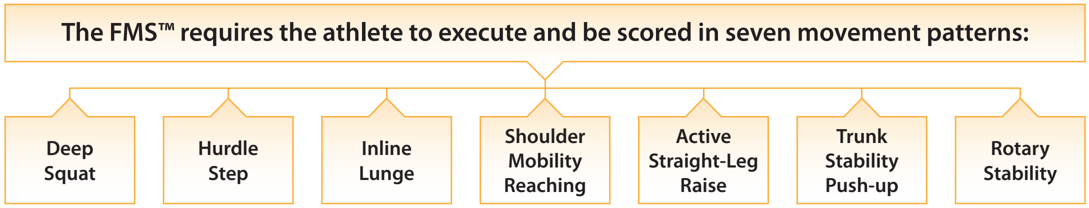
Davies Test



Functional Movement Testing

As mentioned in Chapter 1, the HRCF are considered rudimentary athletic attributes, but they do not differentiate conceptual athleticism. In other words, if a person did not score well in some of the tests it does not necessarily mean they lack the capacity to execute athletic movements during competition. In fact, some athletes are over-fat, inflexible, and may have low cardiovascular fitness, but still succeed in their sport. Whereas others exhibit high performance capacity in exercise assessments but are not at the same level "athletically" during competition. As a result, coaches may benefit more from testing functional capacity as part of an athlete's muscular fitness rather than simply using "standard test" protocols. For the purposes of this text, functional capacity is not a measure of oxygen use, but rather sport movement efficiency during actions that simultaneously challenge ROM, stability, balance, and proprioception [18,19]. There are a number of tools that can be used to measure functional movement. Recently, the Functional Movement Screen (FMS™) has gained popularity among strength coaches as an assessment battery to measure quality of fundamental movement patterns in professional sports, particularly in football; where it has not only been shown to be a performance indicator but also an injury prediction tool [20].

Figure 3.12



Athletes are scored from 0-3 on each of the seven movement patterns:

- A score of 3 represents movement proficiency
- A score of 2 indicates there is some form of compensation
- A score of 1 indicates the athlete cannot perform the movement
- A score of 0 is assigned when the athlete experiences pain during the assessment

A study of 46 professional football players demonstrated an average FMS™ score of 16.9 out of 21 possible points, with a standard deviation of 3.0 [20]. Interestingly, the average pre-season score of those athletes who suffered an injury significant enough to assign them to the injured reserve list for a period of at least 3 weeks was 14.3. This was more than three points lower than the average score (17.4) of those players who were not injured during the following season [20]. While each test has not necessarily been validated for a specific metric, the collective information is useful. A caveat to the FMS™ is that while the protocol has good test-retest reliability when the same tester is used, it has poor inter-rater reliability [21].

The Deep Squat Test of the FMS™ is similar to the popular overhead squat assessment. The athlete begins the test by standing up straight with his/her feet shoulder-width apart, toes facing forward. The athlete is asked to hold a dowel rod with 90° of shoulder abduction and 90° of elbow flexion and then press it over their head [22]. From this start position, the athlete must squat down at least to the point where their femur drops below 90° (relative to the floor) with their heels maintaining ground contact. The athlete should be coached to try to keep their knees over their toes to minimize shear forces on the knee or excessive forward/backward motion [22]. Additionally, the athlete should keep the bar above their shoulders with effort to keep the trunk straight. If he or she completes the movement as described they receive a score of 3 per the FMS™ guidelines. If the athlete was not able to perform the movement, he or she then tries to complete the squat while standing with their heels on a 2 x 6 board to accommodate ankle ROM. If the athlete is successful with this modification, he or she receives a score of 2; if they fail, a 1 is given. If the athlete feels pain at any point, he or she receives a zero. Illustrations of this are provided in Figure 3.13.

Figure 3.13 Examples of the FMS™ Deep Squat Scoring System [22]

The data obtained from a Deep Squat assessment may be helpful, but that ultimately depends on what the coach does with the findings. Coaches must understand that athletes who score the same, or differently, may have different needs to be addressed. For example, athletes who score 3 have greater dorsiflexion excursion, greater peak knee flexion, and greater knee flexion excursion (oscillation) compared to those who score 2. Excursion describes the ability for more movement from one position to another and back to the original position during the test. Those who score 2 demonstrate greater peak knee extension moment force, or more force during rotation of the knee joint, compared to those who score 1 [22]. Looking at the hip, athletes scoring 2 or 3 have greater peak hip flexion, hip flexion excursion, and peak hip extension moment force compared to those who score a 1 [22]. Knowing these differences allows the strength coach to design joint- or movement-specific corrective strategies to improve the functionality of athletes scoring 1 and 2 - if they can recognize what each "biomechanical performance" (correct or compensated) means.

A more detailed analysis in terms of ROM and stability can be implemented using formats such as the one proposed by Noda & Verscheure (2009) which examine the overhead squat. For example, an outward shift of the knees during the overhead squat correlates to poor hip internal rotation ROM, whereas a heel lift during the movement relates to restricted ankle dorsiflexion movement [23]. Additionally, biomechanical analysis from different views provides greater details. Anterior views allow for variations in the frontal plane to be observed, such as an inward knee or foot pronation. Lateral views identify sagittal compensation such as forward arms or trunk, while a posterior view is used to identify hip translation or lumbar scoliosis. Therefore, rather than simply scoring an item, it makes much more sense to dissect the observational data into the specific compensatory issues to establish a corrective strategy. Again, videoing the athlete during the test allows for a more comprehensive analysis of performance.

Table 3.5 Observational Data during Performance of the Overhead Squat

Common Observations	Potential Tightness	Potential Weakness
Feet externally rotate	Soleus, lateral gastrocnemius	Medial gastrocnemius, tibialis posterior
Feet flatten out	Peroneal complex	Tibialis posterior
Heel rises	Soleus	Anterior tibialis
Hip abducts	Piriformis, iliopsoas, sartorius, biceps femoris	Adductors, semitendinosis, semimembranosis
Hip adducts	Adductors, medial hamstrings	Gluteus maximus, gluteus medius
Hips internally rotate	Medial hamstrings, TFL, IT band, gluteus medius	Deep gluteal hip rotators
Lumbar hyperextension	Iliopsoas, lumbar erectors, latissimus dorsi, quadratus lumborum	Gluteals, rectus abdominis, obliques
Lumbar flexion	Obliques, hamstrings, rectus abdominis, adductor magnus	Iliopsoas, lumbar erectors, latissimus dorsi, quadratus lumborum
Protruded abdomen	Iliopsoas, lumbar erectors, quadratus lumborum	Rectus abdominis, obliques, gluteus maximus, transverse abdominis
Arms forward	Latissiums dorsi, pectorals, upper abdominals	Rhomboids, mid trapezius, thoracic extensors
Elbows bent	Pectoralis major, latissimus dorsi	Infraspinatus, teres minor, mid trapezius
Shoulder blade winging	Pectoralis major, serratus anterior	Mid trapezius, rhomboids

Figure 3.14 Observational Analysis during the Overhead Squat

Overhead Squat Test

☐ No Dysfunctions Noted

L	Front View	R
☐	Foot Turns Out	☐
☐	Knee Shifts In	☐
☐	Knee Shifts Out	☐

Side View

☐ Heels Lift
☐ Excessive Forward Lean
☐ Low Back Arch
☐ Low Back Rounds
☐ Arms Fall Forward

L	Rear View	R
☐	Foot Flattens	☐
☐	Asymmetrical Weight Shift	☐

Flexibility Testing

The attainable ROM at a joint affects the way the joint functions and performs. Therefore, maintaining an optimal level of flexibility allows for efficient movement at various velocities and a high level of joint health.

For the purposes of this text, flexibility and ROM will be used synonymously. This understanding is appropriate because flexibility is measured using an articulation site as the reference point for range of motion. In some cases, the measurement is quantified by angular units or degrees of movement. In others, the measurement is linear, often expressed as a distance covered in centimeters or inches. Regardless of how flexibility is quantified, it still reflects the ability of a joint to move around its axis. The attainable ROM at a joint affects the way the joint functions and performs. Therefore, maintaining an optimal level of flexibility allows for efficient movement at various velocities and a high level of joint health. This is a relevant concept because ROM assessed during a static or postural evaluation may differ in a joint when dynamic actions are applied. This is due to fascial extensions across body segments and variations in tension across the kinetic chain at different angles. The overhead squat assessment described earlier is a good example of this phenomenon. An athlete may pass the shoulder flexion test by attaining 180° (humeral movement between the mid-axillary line in the sagittal plane during static posture), but then fail to maintain humeral ROM during the overhead squat. This is due to the change in hip and trunk angles during the movement which increase the pull from the latissimus dorsi on the humerus. An athlete with proper ROM when performing a military press may fail at the receive component of a snatch for the same reason. Therefore, implementation of a complete evaluation that incorporates the core lifts is important for gaining insight into an athlete's risk for movement compensation and associated injury.

Figure 3.15 Muscles with a Greater Risk for Creating Movement Compensations

Hamstrings	• Can create limitations during deadlifts, RDLs, goodmornings, and numerous pulls from the floor • Contributes to pelvic instability with hip flexion
Pectorals and internal rotators	• Can create limitations during overhead movements, sagittal plane upper-body lifts, and snatches
Thoracolumbar fascia	• Can create limitations during trunk flexion and rotation exercises • Can contribute to pelvic and hip instability
Latissimus dorsi	• Can create limitations during the Olympic lifts; particularly clean receives and front squats when the triceps are also tight
Hip flexors	• May limit sagittal plane leg activities and internal trunk function via inhibitory characteristics • Can create compensations during split stance work such as lunges, Bulgarian squats, and split squats

Muscle strength balance is a vital component to athletic performance as addressed earlier. A lack of balance in muscle strength and flexibility at a joint has been implicated in a variety of injuries. One key factor to consider is postural asymmetry. Tight muscles pull on bony structures; distorting normal alignment. When the kinetic chain is compromised, soft tissues become stressed due to force variations that do not exist when the joint is properly aligned. This presents two problems that promote joint injuries. The first problem is that changes in biomechanical alignment associated with tightness cause movement deviations that can lead to undue stress on connecting structures [24]. This is why a runner with a hip joint issue can develop a knee injury if he or she continues to train without addressing the musculoskeletal issue associated with the hip. The second problem occurs when movement inefficiency exists due to an ongoing compensatory stress and the body is subjected to repeated forces that lead to exhaustive strain. Some common examples of alignment alterations are an anterior shift of the shoulder, called upper cross syndrome, and pelvic instability due to a compromised pelvic tilt position. Both musculoskeletal misalignments can cause joint discomfort and may lead to chronic pain. Lower back pain in particular is often associated with lack of flexibility in the muscles that act on the hip and lower spine [25]. Additionally, tight musculature is subject to injury when the joint is forcibly moved through a functionally-unattainable movement range - particularly at high velocities. Overall, a lack of flexibility due to skeletal imbalances and alignment issues often lies at the root of muscle strains and connective tissue sprains in sports [26].

The variability among joint ROM requires a battery of flexibility assessments to determine deficiencies that may exist throughout the body. Ideally, each joint movement should be examined using direct assessments that measure rotational range in degrees of movement. Goniometer, inclinometer, and flexometer devices can be used to directly assess joint ROM with quantifiable data. These measures are more commonplace for individual athletes at high levels, but should still be considered as part of a player evaluation at the collegiate level and up. In some cases, the team athletic trainer or physical therapist can be recruited to perform these assessments as part of the continuum for athletic readiness for a team or player.

Direct measurement using a goniometer is an effective means for assessing flexibility when the tester is familiar with the anatomical sites examined during assessment, and performs subsequent retests for reliability. The goniometer is a protractor-like device that uses a stationary arm fixed at 0° with a movable arm that is aligned with the bone of the movement limb or body segment. The goniometer's axis of rotation is aligned over the joint's axis with the arms of the instrument placed over bony landmarks along the longitudinal axis of the body segments. The technique requires the body segment to move through its full ROM. Upon reaching the terminal position, the goniometer is placed over the respective bony landmarks and the degree of movement is measured and recorded.

Validity and reliability is contingent upon strictness to protocol and technician expertise. Primary errors include improper alignment of the rotational axis or reference to incorrect bony landmarks. Some joints, particularly in the lower body, present more difficulty in attaining true validity compared to upper body measures. When compared to radiography (internal bone imaging), properly-employed goniometer technique shows high levels of validity. One key aspect common of all flexibility assessments that can benefit reliability is to take pictures during the pre-test to assure the sites are used appropriately in the post-test.

In terms of the testing, strength coaches must understand that the measurements should be sport-specific, with some joints being prioritized due to their respective association with sport movements. For example, shoulder flexion, shoulder internal rotation at 0° of abduction, and wrist flexion should all be measured among elite tennis players as these movements were shown to be related to higher speed serves [27]. From a logical coaching perspective, it may be more beneficial to improve these flexibility variables among elite tennis players to high levels versus emphasizing strength or power training for improved serve performance. Understanding these athletes already possess elite serving capabilities, and that research shows that faster serving speeds are directly correlated with a greater functional movement range; maximizing ROM in these areas makes the most strategic programmatic sense.

Consistent with the tennis example described above, a swimming evaluation should prioritize shoulder flexion and extension ROM as stroke mechanics are dependent upon shoulder joint proficiency. Furthermore, coaches who work with upper level baseball players should recognize that pitchers are able to produce more power compared with position players when throwing the ball due to greater external rotation of the shoulder (9° average) [28]. Figure 3.16 illustrates goniometric measurements which may benefit athletes in these sports.

Figure 3.16 Shoulder Analysis for Throwing/Swimming Using a Goniometer

Goniometer-derived data can be used for evaluation of movement range, to compare bilateral movements for disparities, and to serve as baseline measurements for comparative use during later evaluations. The values should be compared to norms that exist for competitive-level ROM for each of the movements (and by position) to see what the athlete needs in terms of improving movement-specific ROM.

The following table provides data from 46 MLB baseball pitchers (mean age of 22 years) which can be used as normative values [29] (Ellenbecker et al., 2002).

Table 3.6 Glenohumeral Joint Rotation Capacity among MLB Pitchers

Movement	Dominant Arm ROM	Non-Dominant Arm ROM
External Rotation	103.2° ± 9.1 (1.34)	94.5 ° ± 8.1 (1.19)
Internal Rotation	42.4° ± 15.8 (2.33)	52.4° ± 16.4 (2.42)
Total Rotation	145.7° ± 18.0 (2.66)	146.9° ± 17.5 (2.59)

Standard error of the mean in parentheses

When evaluating comparative data, coaches must be cognizant of the level of play as well as the age of the athlete being used for comparison. For instance, it would be inappropriate to expect a high school pitcher to reflect MLB measures. It makes more sense to keep athletes near the top of their respective level using normative data. If no "same level" data is available, a coach may use the next level data as a metric for improvement. For instance, if a junior tennis coach knows that glenohumeral joint ROM is related to rotation velocity during a serve among elite players, he/she might start evaluating the younger athletes and compare them to same-level athletes for goal-setting and adequate progression. It would make little sense to attempt to attain the ROM demonstrated by older elite athletes without proper progression strategies applied to all of the interrelated variables. Having excellent ROM without the rest of the requisite attributes will not make the athlete serve faster, and may actually create negative changes in performance.

The following table provides glenohumeral joint data from 117 elite junior male tennis players (mean age of 16 years) participating in Player Development programs with the United States Tennis Association (USTA) [29].

Table 3.7 Glenohumeral Joint Rotation ROM among Elite Tennis Players

Movement	Dominant Arm ROM	Non-Dominant Arm ROM
External Rotation	103.7° ± 10.9 (1.02)	101.8° ± 10.8 (1.01)
Internal Rotation	45.4° ± 13.6 (1.28)	56.3° ± 11.5 (1.08)
Total Rotation	149.1° ± 18.4 (1.73)	158.2° ± 15.9 (1.50)

Standard error of the mean in parentheses

In addition to direct measurements using goniometers, there are also indirect measurement methods that exist for ROM evaluation. Many are more popular among coaches due to the relative ease of use as well as the limited technical skill and equipment required. In most cases, a linear measuring instrument such as a tape measure or degree map is used to quantify ROM during a select battery of sport-specific field tests. Some of these field tests have more merit than others, and only in some cases are they specific to a given sport. The sit-and-reach and its successors including the V sit-and reach, modified sit-and-reach, back saver sit-and-reach, and modified back saver sit-and-reach have all been used as principal measures of flexibility in some sports. These tests are supposed to assess low back and hamstring ROM, but as evident by the number of modifications to the original test, may not be as valid as they are reliable. Most coaches and athletes recognize the short-comings of these tests based on variations in limb length and observable motion segment variations. Likewise, these tests often require subjective data collection to demonstrate where the limitation exists, as several joints are involved.

Indirect measurements have come under scrutiny as it relates to their validity and predictability of performance, but they may still be a valuable tool in understanding if limitations exist. To complicate test selection even more, some tests are limited to sport-specific evaluations and may also be gender-specific. For instance, the sit-and-reach test has actually been shown to have a direct relationship with running performance when used with female track athletes [30], but to be inversely related to running economy among elite male long-distance runners [31]. This could mean stiffer hamstrings may reduce the aerobic demand of longer endurance running by increasing the elastic energy return during the shortening phase of the stretch-shortening cycle (SSC) [31] and/or that the relationship between running economy and flexibility among females may be different than among males [30]. This is not to say that long-duration running is improved by stiffer muscles, but rather that sport-specific ROM tests must be joint-specific. For instance, even though hamstring and lower limb joint tightness is generally associated with greater running economy [31, 32, 33], an increase in hip flexion and hip extension ROM has been shown to improve running economy at different submaximal values (>80% VO_2max) [34].

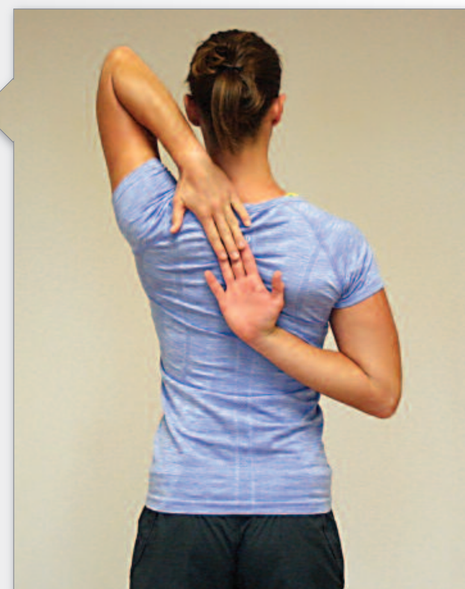
The following field tests can be potentially useful for assessing general ROM and movement limitations within the major problem areas of the kinetic chain.

Back Scratch Test

Assessed Structures: rotator cuff, latissimus dorsi, and triceps brachii

Directions:

- The athlete begins by standing with an upright posture and placing one arm behind the back, and the other arm over the shoulder
- The coach should instruct the athlete to either:
  - Touch the fingertips between their scapula
  - Bring the closed fists together as close as possible between the scapula
- The coach measures the distance between the tips of the middle fingers or the closed fists
  - Normal ROM is fingertip contact or the knuckles being one fist-length apart
- The assessment must be repeated in the opposite direction
- Flexibility evaluation is categorized as either good, borderline, or needs work
  - Capacity will very often differ from left to right side
  - Each motion should be evaluated bilaterally
  - Lower limb limitations reflect tightness in the deltoid, infraspinatus, and joint capsule
  - Upper limb limitations reflect tightness in the internal rotators (pectorals and subscapularis), triceps, and latissimus dorsi



Thomas Test

Assessed Structures: ilipsoas

Directions:

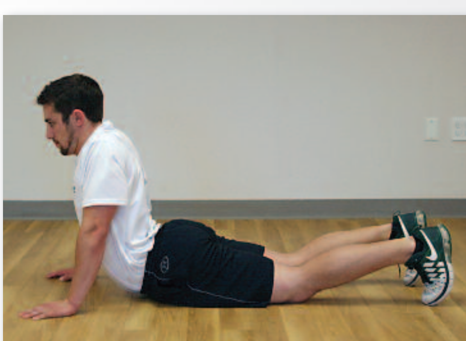
- The athlete lies in a supine position on a table or bench and pulls both legs to chest height (~120° flexion)
- He or she then releases one leg under control, slowly extending it off the edge of the table/bench
  - Normal ROM - the hamstring of the released leg comes to rest on the table/bench while the other leg does not move
- The assessment should be repeated with the other leg
- Flexibility evaluation is categorized as either good, borderline, or needs work
  - Capacity will often differ from left to right hip flexor
  - Pelvic instability is evident by a posterior pelvic tilt
  - Flexing the descending leg will identify rectus femoris limitations whereas using a straight leg is more related to assessing the iliopsoas

Bilateral Hip Flexion Test

Assessed Structures: gluteals, thoracolumbar fascia

Directions:

- The athlete lies supine on the floor and slowly pulls both knees toward the chest in a controlled fashion (no swinging)
  - Optimal ROM - he or she can align the knees with the chest, while the upper portion of the gluteals and lower back maintain contact with the floor
  - Normal ROM - he or she can align the knees with the chest without any posterior pelvic tilt
- The assessment can also be implemented in a unilateral fashion to examine each gluteal separately without the thoracolumbar fascia but this requires the use of a goniometer and examination of pelvic movement
- Flexibility evaluation is categorized as either: good, borderline, or needs work



Trunk Extension Test

Assessed Structures: hip flexors, abdominals

Directions:

- The athlete lies prone on the floor with the hands directly under the shoulders
- He or she then fully extends the arms while keeping the pelvis (hips) in contact with the floor
  - If the superior portion (or more) of the pelvis comes off the ground, it indicates potential tightness in the abdominals and/or hip flexors
  - Female athletes tend to perform better during this test

   - If the athlete has current lower back pain or associated issues, this test should not be implemented
- Flexibility evaluation is categorized as either: good, borderline, or needs work

Trunk Flexion Test

Assessed Structures: erector spinae

Directions:

- The athlete sits upright on the end of a bench with the hips abducted to 45° to allow for a reaching action between the knees
- He or she flexes the trunk under control to reach back between the hips as far as possible
   - Normal ROM - the athlete can flex forward to a position where the shoulder joints align with the hip joints from a profile view
   - The athlete can completely exhale during the reach but should not be allowed to bounce to reach a further distance
- Flexibility evaluation is categorized as either: good, borderline, or needs work

Knee Flexion Test

Assessed Structures: quadriceps

Directions:

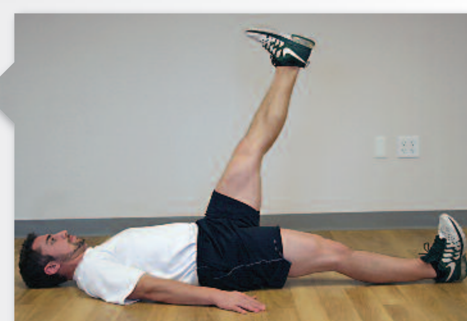
- The athlete lies prone on the floor with the legs together
- He or she flexes one knee in an attempt to pull the heel as close as possible to the gluteal
- The ankle can be grasped using the ipsilateral hand to pull the foot to the gluteal, but the hip should not be abducted or flexed
   - Normal ROM - the heel should come within 2 inches of the gluteal
   - The assessment should be repeated with the other leg
- Flexibility evaluation is categorized as either: good, borderline, or needs work
   - Capacity will often differ from left to right quadriceps
   - Identify if any hip flexion or abduction occurs

Active Straight-Leg Raise Test

Assessed Structures: hamstrings, gastrocnemius

Directions:

- The athlete lies in a supine position on the floor
- He or she flexes one hip to draw the leg towards the chest while keeping the knee fully extended
   - Optimal ROM - the athlete is able to flex the hip at 90° while keeping the knee fully extended and the opposite leg in complete contact with the floor with no external hip rotation

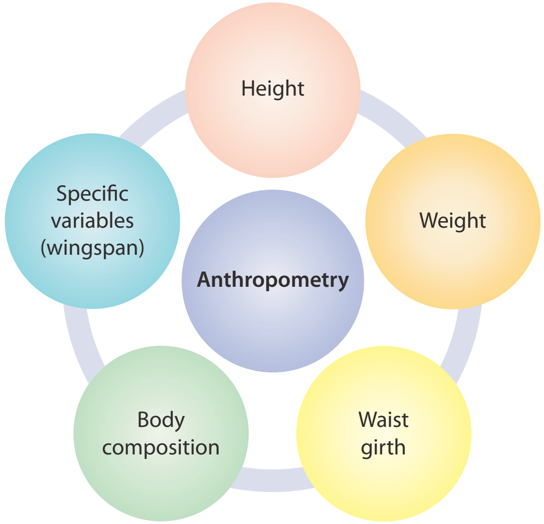


   - Hip flexion ≤70° indicates an increased risk for hamstring strains
   - The assessment should be repeated with the other leg
- Flexibility evaluation is categorized as either: good, borderline, or needs work
   - Capacity will often differ from left to right leg

Anthropometric Measures and Body Composition Testing

Physical, anthropometric, and functional capacities are not completely unrelated. For instance, larger athletes tend to be stronger but also slower, and commonly fatigue earlier than smaller athletes, who may tend to be more flexible. Too often though, assumptions are made based on anthropometric measures which creates bias when making training decisions. Therefore, it is important to differentiate sport-specific requirements for competition, including strength, power, speed, agility, and quickness from anthropometric measurements and functional movement patterns. Anthropometric measurements seek to quantify different dimensions of the human body [35] related to sport capabilities, while functional requirements relate to an athlete's ability to move effectively through the three planes of movement [36].

Figure 3.17



Advances in technology have increased the number of quality anthropometric measurements accessible to coaches. Tools such as three-dimensional (3D) whole-body surface scanners, ultrasound, computerized axial tomography, magnetic resonance imaging (MRI) scans, 3D-motion capture systems, and computerized morphometry can provide greater detail than off-hand measurements such as size and arm length among basketball players or somatotype changes among rugby players [37]. Interestingly, these technologies have been quite revealing when applied in research. Anthropometric measurements conducted on elite-level rowers competing in the Australian Rowing Championships were compared with those of an age-matched sample of general population, non-athletic adults using three-dimensional (3D) whole-body scanning [38]. Not surprisingly, the heavyweight rowers were taller and maintained higher mass than the general population; likewise, the lightweight rowers presented consistent differences from the general population in absolute and proportional size. The greatest differences between elite rowers (heavy and light) and the general population were seen in dimensions that could not be measured without 3D scanning; including segmental volumes and cross-sectional areas [38].

It is well understood that most coaches have limited access to these new technologies; however, they should be considered when available as more traditional methods are limited in their application. For the purpose of this text three different uses for anthropometric testing will be considered:

- Comparing an athlete to norms among his or her elite-level counterparts
- Prediction and correlation of performance implications
- Properly focusing player development for next-level considerations

When conducting anthropometric measurements for elite athletes the methods should be predictive of comparative norms for analysis in the particular sport by position. For example, male elite golfers in the top 90th percentile for height demonstrate a higher drive speed off the tee; indicating those with longer arms hit the ball faster and further. In terms of performance, they also maintain higher averages in number of greens reached during regulation play. Among female elite golfers, greater sitting height (trunk length) actually appears to be detrimental to sand shot performance, but oddly does not affect other shots [39].

The above examples should help a strength coach understand that anthropometric variables can influence performance. Clearly, many anthropometric variables cannot be changed via thoughtful exercise selection (e.g., limb length), but they can identify where natural limitations exist. Therefore, the best use of anthropometric measurements is to identify what affect they have on performance and adjust the training emphasis accordingly. For instance, hip angle and drive distance correlate among golfers; therefore, to account for height limitations an athlete may need to become more explosive. In other cases, recognizing the limitation may warrant effort in other variables which are not influenced or limited by the anthropometric component.

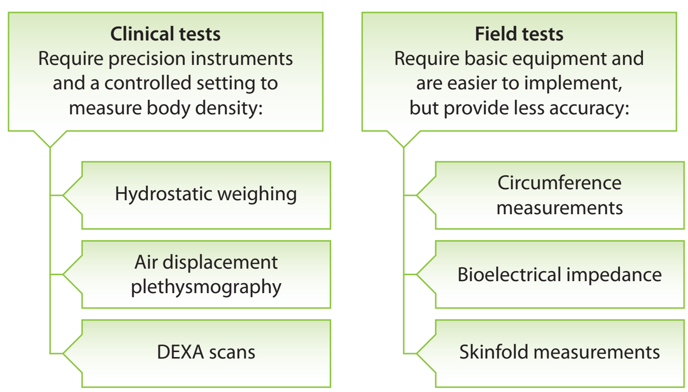
The most common anthropometric variables that derive attention are body weight and body fat percentage, as both can be manipulated. Many sports are negatively impacted by excess weight, but the reason for this may not be the same between two different sports. For instance, heavier American football players' time to exhaustion is faster than smaller and leaner players who play the same position. In golf, larger size tends to improve overall shot distance, but average putt distance after a sand shot appears to be greater among elite male golfers who weigh more relative to height [39]. Therefore, a player like John Daly may drive the ball further but lose match play due to a reduced efficiency in the short game. Since body fat percentage and weight can be measured, monitored, and controlled to a certain extent it makes sense to identify its relevance to the sport and use it to an athlete's advantage. In most cases a higher value, above the requisite for elite play, diminishes performance. This is even true during swimming, where extra buoyancy would seem to be a benefit.

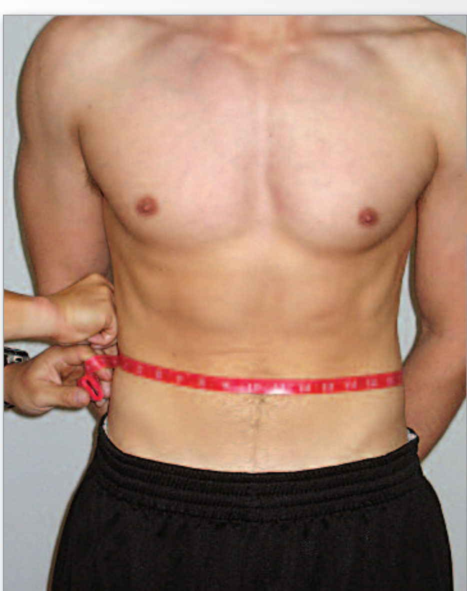
The use of height-weight tables, body mass index (BMI), waist circumference measurements, and the waist-to-hip ratio are simple methods that incorporate anthropometric measures applied to an individual's health status. While useful for the general population, these methods are not helpful among athletes as they do not provide information on body composition, and are consistently less accurate among this population. Therefore, indirect body composition assessments make more sense for athletes. Body composition is the ratio of fat mass to fat-free mass, which can provide more useful information related to performance. When compartment-specific data is properly categorized by tissue type, it provides information concerning the potential of the weight gain or loss. A 3-lb gain of muscle provides the potential for added force production, whereas 3 lbs of additional fat mass adds no such benefit.

It is also important to recognize that the assessment used to determine body composition may be more or less valid and/or reliable when compared to another methodology based on the situation. In some cases, the measurement identifies fat mass by predicting body density, and may not be exceptionally accurate. In other cases, such as with the use of a DEXA scan, the assessment can accurately identify each separate tissue compartment as well as determine bone mineral density (BMD); which is particularly relevant for female athletes. Identifying the actual amount of fat on the body can help determine health risks due to excess or inadequate fat mass as well as provide for a trackable metric so that strategies can be monitored for effectiveness. Performance correlations can also aid in determining the relative ideal mass of an athlete. Identifying the highest performance measurements with corresponding weight and body fat levels can help identify an athlete's ideal "playing weight". Coaches should monitor total body fat as well as regional distribution, and use the data to provide decision-making criteria for the exercise prescription and necessary dietary modifications.

Varying assessment technologies exist for body composition analysis, and each methodology utilizes different means to ascertain body density. Assessments generally fall into two categories: clinical tests and field tests.

Figure 3.18





Circumference Measurements

Often referred to as "girth measurements", this technique simply requires circumference measurements of specific sites throughout the body. The method is easy to perform and requires minimal equipment. The assessment device is often no more than a plastic measuring tape (flexible product is desired). The measured values are charted, graphed, or equated based on the particular protocol being used. Depending upon the estimation model, girth measurements can predict body composition and help determine regional fat storage. The estimations are based on the positive linear relationship between the circumference values of particular anatomical areas and the amount of body fat an athlete generally carries. Girth measurements provide a very practical assessment method for coaches when reliability is more important than validity. When performed correctly with the appropriate prediction equation, circumference estimations of body fat can have a standard error of the estimate (SEE) as low as + 2.5%-4% [40]. They also provide useful information about fat distribution patterns as well as body fat and muscle mass changes during weight loss. Coaches and athletes can easily see and understand the quantifiable differences found between measurements, which often serve as a motivator even when body weight remains unchanged.

Skinfold Measurements

Subcutaneous fat lies between the skin and muscle tissue. The "pinch" is performed at select sites to create a fold of skin and fat with equal parallel sides referred to as a skinfold. Skinfolds at particular locations can be measured and summed to predict body density specific to a given population [41]. It is important to note that there are large inter-individual differences in the patterning of subcutaneous adipose tissue. This is true both within and between genders. Skinfolds can be used because a linear relationship exists among homogeneous groups. This relationship decreases over a wide range, which suggests that the equation used to convert skinfold into a body density must reflect the population being measured [42].

The sum of skinfolds offers a fairly accurate prediction of fat mass; clinical data from criterion measures using hydrostatic weighing suggests that skinfold SEE is approximately 3.5% [43]. Skinfold error is most commonly attributed to testing protocol errors by the technician. This may be due to tester inexperience, variations in tissue consistency, excess fat mass at the site, or incorrect site identification. To improve reliability a coach should perform numerous individual measurements under expert supervision. If a strength coach is inexperienced they should get specific training before using a skinfold assessment to measure body fat. The reason reliability is referred to over accuracy/validity is predictive methods should not be used if true validity is the purpose. Athletes who need true measures should be clinically assessed using a DEXA scan or hydrostatic weighing. Skinfold though is an optimal choice for monitoring fat mass changes among relatively lean athletes.

When deciding on the sites and protocol for a skinfold assessment, it is important to realize that accuracy does not necessarily increase when using more sites. Slight error on each measurement of a seven-site assessment can add up to a significant inaccuracy. What may be of more value is how well the assessment identifies total body storage [44]. Using the Jackson-Pollock generalized equation, the three-site assessment allows for measures at each region of the body [41]. This can identify a high storage depot that may be missed when using other skinfold models. A good rule of thumb is that the assessment should at least measure one of the primary storage areas related to gender-specific storage. For women, a lower body site should be included in the assessment; for men, it should include either the abdominal or subscapular sites. For purposes of reliability, the same tester and site protocol should be used during any follow-up evaluations.

Skinfold assessment should be performed on individuals who are not visibly obese. Individuals who maintain excessive fat mass or have significant storage at the selected sites are difficult to properly assess. This is particularly true when they are also muscular, common of American football lineman. In some cases, accurate folds cannot be made due to high levels of fat mass or the tightness of the skin. If the assessment cannot be performed with relative test accuracy, the data is of little use. In this case, an alternate assessment technique should be used. Additionally, skinfold predictability can be complemented using additional girth measurements [45].

An element of both validity and reliability in skinfold is that the equipment be accurate. The pressure of the calipers should be calibrated to 10 g/mm^2 [41]. The particular brand used is often based on professional preference and budget. It is not recommended to use calipers that require the tester to manually pinch the fold with the instrument due to tension variations which may over or under-compress the fold [41].

Figure 3.19 Technique for Increasing Skinfold Assessment Validity and Reliability

Skinfold Technique:

- Ensure the athlete does not have any cream or lotion on the skinfold sites (wipe off sites as needed)
- Correctly identify the sites to be used (including gender-specific) and mark the fold locations for reliable subsequent measures
- The right side of body is generally used for consistency
- Using the left hand in a thumb-down position, grasp the skinfold with the index finger, middle finger, and thumb and push into the tissue until the underlying muscle can be felt
- Firmly pull the skinfold away from the muscle, making sure it is uniform and has parallel sides
- Use the right hand to hold the calipers with a pronated grip and pull the trigger with the index finder to open the measurement arms
- The caliper arms should be placed just below the fingers, in the center of the fold and held at a perpendicular angle
- While maintaining the pinch with the fingers, release the caliper trigger and assess the measurement within 2 seconds; do not let go of the fold while the reading is being made
- Immediately record the value
- Measure each site twice for accuracy, allowing 15 sec between subsequent measures at each location
- If the value differs by more than 1-2 mm during the second measurement for a given site, measure the site a third time and calculate an average if necessary
- Add the sum of the skinfolds and apply the score to the correct population-specific equation

The following gender-specific 3-site protocols are commonly used among athletic populations:

STEP 1 – Measure the Skinfolds



Male athletes:

Chest: diagonal fold taken one half the distance between the anterior axillary line and the nipple

Abdomen: vertical fold taken about 1 inch to the right of the umbilicus

Thigh: vertical fold taken on the front of the thigh midway between the hip (inguinal crease) and the superior aspect of the patella

Female athletes:

> **Triceps:** vertical fold taken halfway between the acromion process of the shoulder and the inferior part of the elbow on the rear midline of the upper arm
>
> **Suprailiac:** diagonal fold taken with the natural angle of the iliac crest at the anterior axillary line immediately superior to the iliac crest
>
> **Thigh:** vertical fold taken on the front of the thigh midway between the hip (inguinal crease) and the superior aspect of the patella

STEP 2 – Calculate Body Density and Body Fat

To calculate body fat, the strength coach must first ascertain body density using the Jackson-Pollock equation.

Male athletes:

> Body Density = 1.10938 – (0.0008267 x the sum of the chest, abdomen, and thigh skinfolds in mm) + (0.0000016 x (the sum of the chest, abdomen, and thigh skinfolds in mm)^2) – (0.0002574 x age)

Female athletes:

> Body Density = 1.0994921 – (0.0009929 x the sum of the triceps, waist, and thigh skinfolds in mm) + (0.0000023 x (the sum of the triceps, waist, and thigh skinfolds in mm)^2) – (0.0001392 x age)

Then, the body density is converted to a body fat percentage using the Siri equation

Male and female athletes:

> Body fat = [(4.95/body density) - 4.5] x 100

Strength coaches should compare findings with sport-specific data to decide what the goals should be in terms of body fat percentage for each athlete. They may also want to correlate the data with other factors. For example, more than 200 professional baseball players were tested for a comparative basis between positions using body composition and running speed and the following data was found:

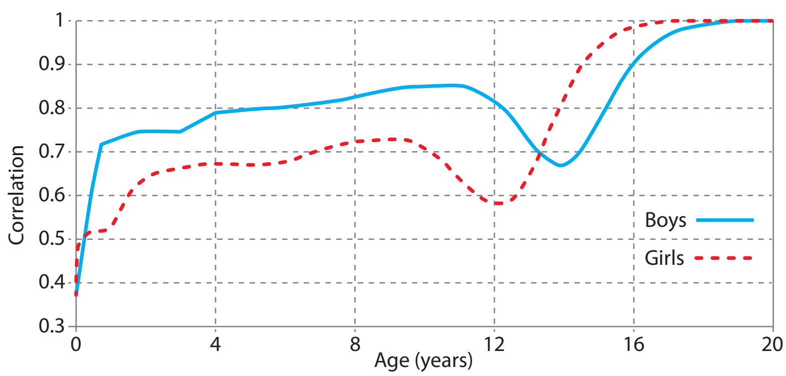
- Outfielders averaged 8.36% body fat and performed the 60-yd dash in 6.89 seconds
- Infielders averaged 9.33% body fat and performed the 60-yd dash in 6.97 seconds
- Catchers averaged 9.71% body fat and performed the 60-yd dash in 7.09 seconds [46]

Clearly, the players' body composition and running speed were more indicative of the movement patterns required by their positions. Not surprisingly, pitchers averaged 10.40% body fat [46].

By this point the coach should understand that each sport has anthropometric requirements that need to be taken into account when making coaching decisions such as the position an athlete might be best suited for. It is also important to remember that "size" is a single piece of the puzzle and that players seemingly limited by anthropometric measurements may still succeed at a particular sport or position if other aspects can be developed. Strength coaches should be aware of how anthropometric limitations affect play and prepare an athlete to compensate for them. For example, according to the NBA, one of the shortest players at the 2013 combine was DeShane Larkin, currently playing for the Dallas Mavericks, at 5'10.25" without shoes (only 5 players out of 63 were under 6 feet tall) [47]. However, Larkin's 44-inch vertical jump was the highest in the combine, and one of the top performances in combine history; in addition his three-quarter court sprint time of 3.08 seconds was the fastest for the combine. The point here is that if anthropometric measures fail to reflect the positional norm, other performance components need to be overly-emphasized to achieve elite levels. The key is identifying which performance metrics are necessary to replace the anthropometric limitations. In most cases a historical review of the sport provides this data. Surprisingly even sports with seeming heterogeneity in anthropometric requirements such as soccer need to be looked at carefully. Evaluations of elite European players have shown that goalkeepers and central defenders are usually the tallest at around 6'3", and heaviest at around 192.7 lbs; while midfielders are the shortest at around 5'9", and lightest averaging 162.8 lbs [48, 49]. This notable difference shows how important it is to be position-specific in terms of player development when looking at anthropometrics; particularly when considering an athlete's playing-level potential. Anthropometric measures increase in relevance as level of play increases.

When considering height, mass, and other anthropometric measures for youth sports, coaches need to recognize that there are some major limitations. Most notably, young athletes follow different maturation curves that can complicate an analysis. In any case, research has demonstrated correlations between height during youth and an anticipated height (as well as other anthropometric variables) during adulthood, as seen in Figure 3.20.

Figure 3.20 The Correlation between a Child's Current Height and their Adult Height, by Age and Sex [50, 51]



Commonly, anthropometric measurements are used with other variables to test a young athlete's capacity to perform, and to properly classify them for similar playing-level grouping during practice or competition. Researchers used statistical multiple regression analyses that included 32 anthropometric variables, height, and chronological age to predict the abilities of an athlete to generate force and power (or what the investigators called impulse). Using this analysis they proposed a formula that can generate impulse values, ultimately using only three anthropometric variables for males and females: height (HT), forearm girth (FAG), and calf girth (CAG) [52].

Young Males:

Impulse = -2,895.3 + 10.48(HT) + 16.25(age) + 74.78(FAG) + 19.27(CAG)

Young Females:

Impulse = -2,378.0 + 9.63(HT) + 7.71(age) +14.88(FAG) + 52.61(CAG)

There is no normative data associated with impulse values; however, they might be beneficial to:

- Account for differences in physical maturity independent of age
- Make competition and training more equal, which is a key factor in maintaining commitment to a sport among youth
- Provide a basis for future performance capacity

Coaches must also understand that by the age of 14 years many females will have matured physically and therefore maintain a reduced improvement potential in terms of growth and natural physical development; males on the other hand may still show considerable improvements related to anthropometric growth up to 18 years of age [52].

Assessments for the Performance-Related Components of Fitness (PRCF)

Power, speed, agility (quickness), balance, and coordination are considered the pillars of athletic performance. Each of these PRCF relies heavily upon the nervous system, and should be evaluated in a manner that accurately separates the contributing factors. As mentioned earlier the intention of this chapter is not to provide an exhaustive list of tests but rather avail the tools necessary for coaches to design their own testing batteries based on the specifics of each scenario.

Power Testing

Power is one of the most desirable attributes for sports as it affects acceleration and speed. Many people confuse strength with power, assuming if an athlete can bench or squat heavy loads they are powerful. This is not exactly true because power speaks to the rate work is performed, not the actual amount of work. Coaches should strive to increase strength for the purposes of power and use power for acceleration and speed. Testing power, like other physical attributes requires movement-specific assessments, because a single test (e.g., vertical jump) does not adequately define the capabilities of the whole body. For power testing there are not many validated assessments with normative data, particularly for the upper body. The tests are also complicated by the need to measure movement rate to truly calculate a value. Additionally, there is a difference between peak power measures and anaerobic capacity placing further emphasis on the quality of the data from the selected test.

Lower Body Power Assessments

Lower body power assessments have normative data for tests that measure vertical and horizontal displacement; in the case of the Margaria-Kalamen power test, both can be evaluated. Likewise, enough data exists for level of play comparisons and predictions, particularly with the vertical and broad jump tests. In some cases, power tests for the lower body require somewhat complicated testing equipment to measure peak power as movement rate must be determined; in others a single measurement is used for comparison across an athletic population.

Margaria-Kalamen Power Test

The original protocol for this test requires the athlete to run as fast as possible up a nine-step staircase, 1.575 m in total height (each step is 17.5 cm), leaping three steps at a time with a 6 m running start [53]. While this protocol might still work for the general population, sports coaches need to modify it for athletes. The original protocol demonstrated that 0.5-1.0 seconds is required to measure peak speed during stair climbing, but today's athletes can complete the original test in under 0.5 seconds; making the measurement less valid [54]. An athlete-specific modification to the test involves performance of the same initial 6 m running start, but requires the participant to run up 20 steps instead of nine (3.12 m vertical distance vs. 1.575 m); and contact every other step instead of every third. The starting position and the even-numbered stairs should be marked with different colors to ensure the athlete knows exactly where to step. A timing mat or photocell activated by the athlete can be used to measure time elapsed during the run. The measured time starts when the athlete touches the initial step (2nd step), and stops when the athlete contacts the last (20th) step. The athlete usually performs the test three times and the strength coach records each trial to the nearest thousandth of a second to calculate power as follows [54, 55]:

$$\textbf{Power (W)} = \frac{\text{body mass (kg) x vertical displacement (m) x 9.8}}{\text{time (s)}}$$

Jump Tests

Figure 3.21

The most common/popular jump tests for measuring power include:

- **The Sargeant jump test**
- **The countermovement jump test (CMJ)**
- **The broad jump test**
- **The squat jump test (SJ)**

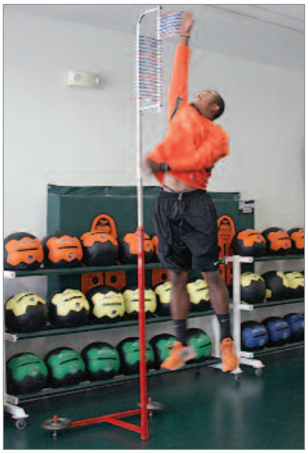
Jump tests are the most commonly used assessments to measure power within athletics. The Sargeant jump test, countermovement jump test (CMJ), broad jump test, and the squat jump test (SJ) all provide different data and may be more or less suited for a particular sport. For instance, an infield baseball player must often jump maximally to stop a ball from going to the outfield; requiring the highest single-arm vertical reach (reflective of the Sargeant jump test). This differs from a volleyball player who must block shots using maximal jumps with both arms extended. To the contrary, the CMJ removes vertical force generated by the arms making it more practical for soccer; whereas in American football horizontal power is an important component (broad jump is used in the combine). Coaches should make selections for jump tests based on the sport or position played and use the data to monitor programmatic influence.

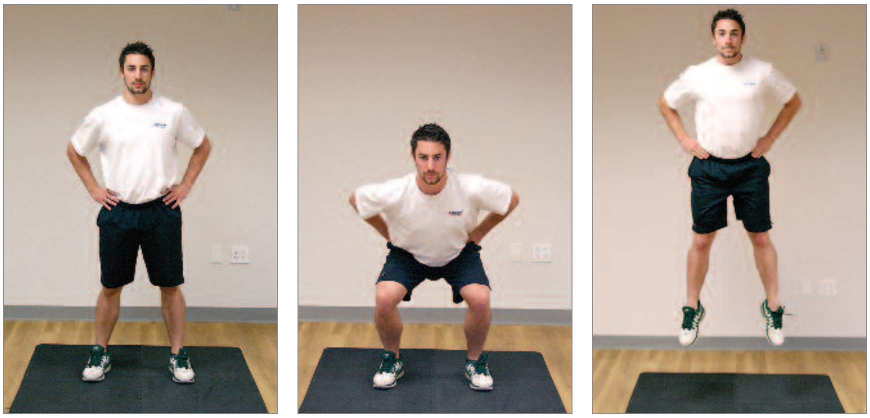
The Sargeant jump test is a vertical jump and reach test, thus it involves determining jumping capacity by subtracting standing reach height from jumping reach height. To identify the maximal reach height an athlete will stand flat footed with their feet under their hips, and reach upward as high as possible using the same arm that he or she will reach with during the jump. The height is marked and recorded by the coach; the athlete is then asked to perform a maximal jump, with the highest reach being recorded. The vertical jump distance is the difference between standing reach height and the highest jumping height. Generally, three jumps are used, with the highest jump value utilized for determination of anaerobic power output. A key characteristic to this test is that countermovement is allowed (to exploit the SSC), and arm swinging is permitted during the jump. The Sargeant jump test has been shown to be a valid and reproducible assessment for measuring explosiveness for whole sport teams [56].

The CMJ and SJ tests do not use reach to measure the distance jumped but rather contact plates to determine time off of the ground. The CMJ is similar to the Sargeant test, but prohibits arm swinging by having the athlete place his or her hands on their waist. This differs from the SJ test which further removes SSC benefits as it eliminates both the lower body countermovement as well arm swinging. The starting position for the SJ test is with the knees flexed at a 90° joint angle. It is recommended that coaches have the athlete hold this initial position for at least 2 seconds to best control for any countermovement. The broad jump (or long jump) is a useful tool in assessing horizontal displacement capabilities relative to mass. Due to the fact that many sports require both vertical and horizontal power, the ability to maximally jump forward for distance has predictive carry-over to sport activities. In American football many of the top picks in the draft have top 25th percentile scores in vertical and horizontal jumps.

Sargeant jump test protocol:

- This assessment is also referred to as the no-step vertical jump test
- The easiest way to conduct this test is using chalk
- The athlete has their fingers on the right hand marked with chalk
- The athlete stands next to a wall on their right side and extends their arm above their head; the wall is marked at the highest point he or she can reach with the chalk on their fingers
- The athlete performs a jump beginning with a rapid countermovement action, descending to an athletic (or power) position
  - The coach should make sure that the ROM for testing is sufficient, since a shallow countermovement will not result in maximal jump height
- The athlete must also use the upper extremities for a sudden upward impulse to achieve the highest vertical jump
- At the highest point of the jump, the athlete must mark the maximum height they can reach with the chalk on their fingers
- The jump height is the difference between the two points marked on the wall
- This test can also be performed using a Vertec as shown in the picture below





CJM test protocol:

- The athlete starts standing upright, and performs a jump beginning with a rapid countermovement action, descending to a knee angle of 90°
  - The coach should make sure that the ROM for testing is up to 90° of knee flexion since a shallow countermovement will not result in maximal jump height
- The athlete must hold their hands on their hips during the jump to avoid the use of momentum via upper extremity swinging
- Tucking the knees is not allowed

Broad jump test protocol:

- This assessment is also known as the double-leg long jump
- The athlete stands behind a line marked on the ground with their feet under their hips
- The athlete performs a jump beginning with a rapid countermovement action; the hips should remain slightly higher and further back than an athletic (or power) position to allow for maximal horizontal displacement
- The coach should make sure that the ROM for testing is sufficient, since a shallow countermovement will not result in maximal jump distance
- The athlete must use the upper limbs to create a sudden forward impulse to achieve maximum horizontal displacement
  - In this case, the triple extension must create forward driving force
- The athlete must jump as far as possible and land on both feet without falling backwards

Squat jump test protocol:

- The athlete is instructed to stand with his or her hands on the hips and to bend at the knees, hips, and ankles
  - The athlete should descend to a static position of 90° of knee flexion
- Once in the ready position and motionless, the coach gives a go-ahead signal and the athlete must jump as high as possible while keeping his or her hands on their hips
- Tucking the knees is not allowed
- This jump differs from the CMJ in that the SSC cannot be engaged via a rapid countermovement action

Sport-Specific Normative Data for Jump Tests

Table 3.8 Vertical Jump Performance among Male and Female Basketball Players [58]

Vertical jump tests – descriptions, emphases, and values – means (SD)			
Test	Description/emphases	VJ values – females players (cm)	VJ values – male players (cm)
Counter movement jump – no arm swing (CMJ-NS)	Squatting and leaping with hands on hips or behind back throughout the jump	24.8 (2.5) Pre-training 24.9 (2.6), post training 26.3 (2.9)	40.1 (4.0) 43.9 (4.0) 51.6 (6.9) G: 59.7 (9.6), F: 57.8 (6.5), C: 54.6 (6.9) Pre- training 53.0 (1.3), post training 62.2 (1.2)
Counter movement jump – with arm swing (CMJ-S)	Squatting and leaping with hands moving backwards on the downward motion and swinging up with the leap	G: 47.6 (4.9), F: 47.2 (6.5), C: 47.6 (5.3) G: 49.38 (6.2), F: 49.43 (11.1), C: 43.51 (4.45) G: 48.9 (4.9), SF: 44.5 (4.4), PF: 40.5 (3.8), C: 42.0 (3.0) 45.2 (2.7) Pre-training 39.9 (.9), post-training 43.2 (1.1)	68.1 (8.6)[a] Freshmen: 61.0 (7.4), change to senior + 4.9 Pre-training 59.0 (5.0) post-training 66.3 (5.8) 65.0 (6.1) 64.5 (9.7) 64.4 (7.9)b) Pre-training 61.22 (6.6), post-training 64.8 (5.1)
Squat jump – no arm swing (SJ-NS)	Starting the jump from a static squat position with hands on waist or behind back throughout the jump	21.5 (2.4) Pre-training 21.7 (2.3), post-training 24.2 ± 2.4	39.8 (3.7) 41.5 (3.0) Pre-training 44.8 (1.0), post-training 53.0 (2.0)
Step back before jump	Step back with one foot, crouched positions, hands stretched back – bring feet together, swing arms forward, and leap	G: 45.73[c], F:42.76[d], C:46.6 (4.8)	Elite players 56.6 (4.4), average-level players 51.6 (3.3) G: 63.3c, F: 58.7d, C: 57.9 (8.5)
One-step approach	One step approach with two foot takeoff with arm swing	Pre-training 45.1 (14.1), post-training 48.8 (13.9)	
Two-step approach	Two steps approach followed by a leap on one leg with arm swing		Pre-training 72.64 (7.11), post-training 75.44 (7.37)
G: guards; F: forwards; C: centers; SF: shooting forwards; PF: power forwards	[a] Data from one out of four seasons in that study. [b] Data from one group in study.	[c] SD data not available – data combined for point guards and shooting guards by authors. [d] SD data not available – data combined for small forwards and power forwards by authors.	

Reprinted by permission from Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players--a review of observational and experimental studies. Journal of Science and Medicine in Sport / Sports Medicine Australia, 13(3), 332-339

Table 3.9 Percentile Ranks for Vertical Jump (No Step) among Basketball Players of Various Playing Levels [59]

	HS 14Y		HS 15Y		HS 16Y		HS 17Y		NCAA D1 Males		NCAA D1 Females		NBA	
% rank	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm
90	25.6	65.0	27.1	68.8	29.0	73.7	28.3	71.9	30.5	77.5	21.6	54.9	31.2	79.2
80	23.4	59.4	25.0	63.5	27.5	69.9	26.5	67.3	30.0	76.2	20.1	51.1	29.5	74.9
70	22.5	57.2	24.0	61.0	25.7	65.3	24.5	62.2	28.5	72.4	19.7	50.0	28.4	72.1
60	21.6	54.9	23.0	58.4	24.7	62.7	24.0	61.0	28.0	71.1	18.5	47.0	27.5	69.6
50	21.0	53.3	23.0	58.4	24.0	61.0	24.0	61.0	27.5	69.9	18.0	45.7	27.0	68.6
40	20.9	53.1	22.0	55.9	23.0	58.4	23.5	59.7	26.8	68.1	17.5	44.5	26.2	66.5
30	20.3	51.6	21.5	54.6	22.4	56.9	22.9	58.2	26.0	66.0	16.5	41.9	24.6	62.5
20	18.0	45.7	20.5	52.1	20.9	53.1	21.6	54.9	25.5	64.8	15.9	40.4	23.6	59.9
10	15.4	39.1	20.0	50.8	19.5	49.5	21.0	53.3	24.5	62.2	14.5	36.8	22.4	56.9
$\bar{x}$	21.0	53.3	23.1	58.7	24.0	61.0	24.0	61.0	27.7	70.4	18.0	45.7	26.7	67.8
SD	3.1	7.9	3.0	7.6	3.9	9.9	2.3	5.8	2.4	6.1	2.5	6.4	3.3	8.4
n	21		87		58		22		138		118		40	

HS = high school; $\bar{x}$ = mean

Reprinted by permission from Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics

Table 3.10 Percentile Ranks for Vertical Jump (No Step) among Football Players [59]

	HS 9th Grade		HS 10th Grade		HS 11th Grade		HS 12th Grade		NCAA DIII		NCAA DI	
% rank	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm
90	27.6	70.1	27.4	69.6	28.5	72.4	30.0	76.2	30.0	76.2	33.5	85.1
80	25.5	64.8	26.0	66.0	26.9	68.3	28.0	71.1	28.5	72.4	31.5	80.0
70	24.0	61.0	24.6	62.5	25.5	64.8	26.5	67.3	27.5	69.9	30.0	76.2
60	23.5	59.7	23.9	60.7	25.0	63.5	26.0	66.0	26.5	67.3	29.0	73.7
50	22.3	56.6	23.0	58.4	24.0	61.0	25.0	63.5	25.5	64.8	28.0	71.1
40	21.9	55.6	22.0	55.9	23.5	59.7	23.5	59.7	24.5	62.2	27.0	68.6
30	21.2	53.8	21.0	53.3	22.0	55.9	22.5	57.2	23.5	59.7	25.5	64.8
20	19.3	49.0	19.0	48.3	20.5	52.1	21.5	54.6	22.0	55.9	24.0	61.0
10	17.7	45.0	18.0	45.7	18.8	47.8	19.5	49.5	20.0	50.8	21.5	54.6
$\bar{x}$	22.6	57.4	22.7	57.7	23.9	60.7	25.0	63.5	25.3	64.3	27.6	70.1
SD	3.6	9.1	4.1	10.4	3.5	8.9	4.1	10.4	4	10.2	4.4	11.2
n	30		102		95		114		567		1,495	

HS = high school; $\bar{x}$ = mean

Reprinted by permission from Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics

Table 3.11 Vertical Jump Heights for College Football Players Participating in the NFL Combine [59]

	DB		DL		LB		OL		QB		RB		TE		WR	
% rank	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm
90	40.0	101.6	36.8	93.5	37.0	94.0	33.0	83.8	35.5	90.2	38.5	97.8	37.9	96.3	39.5	100.3
80	38.5	97.8	35.0	88.9	36.4	92.5	31.6	80.3	35.5	90.2	36.6	93.0	36.2	91.9	38.5	97.8
70	37.5	95.3	34.1	86.6	35.0	88.9	30.5	77.5	34.5	87.6	35.0	88.9	35.6	90.4	36.5	92.7
60	37.0	94.0	32.5	82.6	34.0	86.4	29.5	74.9	33.2	84.3	34.5	87.6	34.9	88.6	36.0	91.4
50	36.0	91.4	32.0	81.3	33.5	85.1	28.5	72.4	31.8	80.8	33.5	85.1	34.0	86.4	35.5	90.2
40	35.5	90.2	30.5	77.5	32.5	82.6	27.8	70.6	31.0	78.7	32.5	82.6	33.5	85.1	34.5	87.6
30	34.5	87.6	30.5	77.5	32.4	82.3	27.0	68.6	30.0	76.2	32.0	81.3	31.0	78.7	34.0	86.4
20	33.5	85.1	30.0	76.2	31.0	78.7	26.0	66.0	29.0	73.7	31.0	78.7	30.5	77.5	32.5	82.6
10	32.5	82.6	28.5	72.4	30.0	76.2	25.0	63.5	26.5	67.3	29.7	75.4	28.5	72.4	31.5	80.0
$\bar{x}$	36.2	91.9	32.0	81.3	33.5	85.1	28.8	73.2	31.8	80.8	33.8	85.9	33.6	85.3	35.5	90.2
SD	2.6	6.6	3.5	8.9	2.9	7.4	3.1	7.9	3.6	9.1	3.1	7.9	3.3	8.4	3.4	8.6
n	120		102		65		148		38		73		42		100	
DB = defensive backs, DL = defensive linemen, LB = linebackers, OL = offensive linemen, QB = quarterbacks, RB = running backs, TE = tight ends, WR = wide receivers; $\bar{x}$ = mean																

Reprinted by permission from Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics

Table 3.12 Broad Jump Results for College Football Players Participating in the NFL Combine [59]

	DB		DL		LB		OL		QB		RB		TE		WR	
% rank	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm
90	127.0	322.6	120.8	306.8	125.0	317.5	108.9	276.6	118.5	301.0	126.3	320.8	122.8	311.9	127.0	322.6
80	122.0	309.9	118.8	301.8	122.0	309.9	105.8	268.7	116.0	294.6	122.2	310.4	121.2	307.8	122.2	310.4
70	121.7	309.1	117.2	297.7	117.5	298.5	104.0	264.2	114.0	289.6	120.0	304.8	115.2	292.6	120.3	305.6
60	120.0	304.8	116.6	296.2	117.0	297.2	101.6	258.1	110.0	279.4	119.0	302.3	111.2	282.4	118.0	299.7
50	120.0	304.8	115.0	292.1	116.0	294.6	100.0	254.0	106.5	270.5	116.0	294.6	111.0	281.9	117.0	297.2
40	117.8	299.2	115.0	292.1	114.0	289.6	98.4	249.9	104.0	264.2	114.8	291.6	109.0	276.9	113.6	288.5
30	116.0	294.6	112.6	286.0	112.5	285.8	97.0	246.4	103.5	262.9	111.1	282.2	108.2	274.8	112.0	284.5
20	115.0	292.1	110.2	279.9	111.0	281.9	94.0	238.8	102.0	259.1	110.0	279.4	106.4	270.3	111.0	281.9
10	113.0	287.0	107.2	272.3	106.0	269.2	89.1	226.3	98.5	250.2	108.7	276.1	96.4	244.9	110.0	279.4
$\bar{x}$	119.5	303.5	114.8	291.6	115.8	294.1	99.7	253.2	108.1	274.6	116.5	295.9	111.3	282.7	116.7	296.4
SD	5.6	14.2	4.5	11.4	6.0	15.2	6.8	17.3	7.1	18.0	6.5	16.5	8.3	21.1	5.9	15.0
n	40		15		24		50		14		36		11		38	
DB = defensive backs, DL = defensive linemen, LB = linebackers, OL = offensive linemen, QB = quarterbacks, RB = running backs, TE = tight ends, WR = wide receivers; $\bar{x}$ = mean																

Reprinted by permission from Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics

Table 3.13 Vertical Jump Performance among Italian Male and Female National Team Soccer Players [60]

Team	SJ (cm)	CMJ (cm)	ΔCMJ-SJ (%)	SMJ-SJ (cm)	CMJ:SJ
U17 (n = 21)	37.3 ± 4.7	40.9 ± 5.1	9.7 ± 7.1	3.5 ± 2.4	1.1 ± 0.7
U20 (n = 17)	38.0 ± 4.9	40.2 ± 4.7	6.0 ± 4.1	2.2 ± 1.5	1.1 ± 0.04
U21 (n = 18)	37.0 ± 3.9	40.3 ± 4.3	8.0 ± 6.2	2.9 ± 2.2	1.1 ± 0.1
FNAT (n = 21)	30.1 ± 3.7	31.6 ± 4.0	5.2 ± 4.6	1.5 ± 1.3	1.05 ± 0.05
U19-F (n = 20)	32.8 ± 2.9	34.3 ± 3.9	4.9 ± 2.1	1.5 ± 0.7	1.05 ± 0.12
U17-F (n = 21)	28.2 ± 2.5	29.0 ± 2.1	3.2 ± 2.1	1.0 ± 0.7	1.03 ± 0.09
MNT (n = 56)	37.6 ± 4.44	40.5 ± 4.4	8 ± 6.1	2.9 ± 2.2	1.1 ± 0.1
FNT (n = 62)	29.1 ± 3.3	30.2 ± 3.5	4 ± 3.1	1.1 ± 0.1	1.04 ± 0.1
U, Under; MNT, Male National Team; FNT, Female National Team; FNAT, First National Athlete of Tomorrow					

Reprinted by permission from Castagna, C., & Castellini, E. (2013). Vertical jump performance in Italian male and female national team soccer players. Journal of Strength and Conditioning Research, 27(4), 1156-1161

Table 3.14 Vertical Jump Data for Male and Female Volleyball Players [61]

VJ values among female volleyball players						
Study	Method	N	Age (years)	Proficiency	Apparatus	VJ values (cm)
Barnes et al. (2007)	Ob.	11	19.6 ± 1.4	NCAA Division II	Vertec jump measuring device – measure difference from reaching height to highest hand reach	N2: 31.8 ± 4.6
Ferns et al. (1995)	Ob.	13	19.5 ± 11	NCAA Division I	Vertec jump measuring device	CMJ: 45.5 ± 6.8
Fry et al. (1991)	Ex.	6	19.7 ± 0.5	NCAA Division I team	N/A	45.7 ± 6.9
Newton et al. (2006)	Ex.	14	20.0 ± 1.2	NCAA Division I players	Force plate: record displacement of center of mass	Pre (season start), mid (7 weeks into season), post (11 weeks – end of competition season) AVJ: pre: 61.2 ± 5.6 mid: 57.9 ± 5.3 post: 61.0 ± 5.6
Stech and Smulsky (2007)	Ob.	10	22.0 ± 2.9	High performance players with 8 years of volleyball experience	Contact mat: measuring flight time	AVJ: 47.6 ± 5.6
VJ values among male volleyball players						
Ferthomme et al. (2005)	Ob.	11	26 ± 5.4	First division players	Contact mat: measuring flight time	CMJ: 56.5 ± 4.6
Kollias et al. (2004)	Ob.	24	24.5 ±4.2	Players of national league teams	Force plate	CMJ-NS: 35 ± 4.9
Lee et al. (1989)	Ob.	24	N/A	US National Olympic Festival team players	Vertec jump measuring device- measure difference from reaching height to highest hand reach	CMJ: 69.3 AVJ: 79.8
Newton et al. (1999)	Ex.	Con: 8	19 ± 2	NCAA division I team	Vertec jump measuring device – measure difference from reaching height to highest hand reach	8 – week ballistic resistance training program Con: CMJ pre: 68.1 ± 7.0. post: 69.4 ± 7.4 AVJ: pre: 80.4 ± 6.2. post: 80.5 ±7.4
Stockbrugger and Haennel (2003)	Ob.	20	18.9 ± 1.4	Competitive players	Measured height of jump	CMJ: 62 ± 7
OB., observational study; Ex., experimental study; CMJ, countermovement jump with arm swing; AVJ., vertical jump with approach; Con., Control group; Exp., experimental group						

Reprinted by permission from Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: A review of observational and experimental studies: Vertical jump in volleyball players. Scandinavian Journal of Medicine and Science in Sports, 20(4), 556-567

Table 3.15 Percentile Ranks for Vertical Jump (No Step) in NCAA Division I Female Athletes [59]

	Volleyball		Softball		Swimming	
% rank	in.	cm	in.	cm	in.	cm
90	20.0	50.8	18.5	47.0	19.9	50.5
80	18.9	48.0	17.0	43.2	18.0	45.7
70	18.0	45.7	16.0	40.6	17.4	44.2
60	17.5	44.5	15.0	38.1	16.1	40.9
50	17.0	43.2	14.5	36.8	15.0	38.1
40	16.7	42.4	14.0	35.6	14.5	36.8
30	16.5	41.9	13.0	33.0	13.0	33.0
20	16.0	40.6	12.0	30.5	12.5	31.8
10	15.5	39.4	11.0	27.9	11.6	29.5
$\bar{x}$	17.3	43.9	14.6	37.1	15.3	38.9
SD	2.1	5.3	2.9	7.4	3.0	7.6
n	90		118		40	
$\bar{x}$ = mean						

Reprinted by permission from Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics.

Table 3.16 Percentile Ranks for the Broad Jump among Elite Male and Female Athletes [59]

	Males		Females	
% rank	in.	cm	in.	cm
90	148	375	124	315
80	133	339	115	293
70	122	309	110	279
60	116	294	104	264
50	110	279	98	249
40	104	264	92	234
30	98	249	86	219
20	92	234	80	204
10	86	219	74	189

Reprinted by permission from Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics.

For all jumps, the following formula appears optimal for estimating power (Watts):

The Sayers Equation: [62]

Peak Power = (60.7) × (jump height [cm]) + 45.3 × (body mass [kg]) - 2055

However, there are two other formulas that have been proposed and can also be used:

The Lewis Equation: [63]

Power (kg/m/s) = $\sqrt{4.9 \text{ x } 9.81 \text{ x body mass (kg)}}$ x $\sqrt{\text{jump and reach score (m)}}$

The Harman Equation: [64]

Peak Power = 61.9 x jump height (cm) + 36.0 x body mass (kg) - 1822

Wingate Test

The Wingate test requires the athlete to cycle as hard and fast as possible using a stationary bike (usually for 30 seconds). The coach weighs the athlete just before the test; obtaining the value in kilograms. The resistance is usually equal to 7.5% of the athlete's bodyweight. This load is set using a calibrated plate attached to the stationary bike wheel. After a warm up, the athlete is asked to reach a specified pedaling cadence without resistance (usually 100 RPM), and once he/she reaches this pedaling speed the coach signals the start of the test. The predetermined resistance is added and the athlete is required to perform an all-out sprint while remaining in the seat. Once the testing effort is over, the loading plate is removed and the athlete is allowed to cool down. A number of measurements can be taken including peak power, anaerobic fatigue, anaerobic capacity or total work, and heart rate.

Table 3.17 Wingate Anaerobic Test Classification of Peak Power (W, W/kg) and Anaerobic Capacity (W, W/kg) Among Men [65]

Categories	Peak Power (W)	Peak Power (W/kg)	Anaerobic Capacity (W)	Anaerobic Capacity (W/kg)
Elite	>1,163	>13.74	>823	>9.79
Excellent	1,092-1,163	13.04-13.74	776-823	9.35-9.79
Above average	1,021-1,091	12.35-13.03	732-777	8.91-9.34
Average	880-1,020	11.65-12.34	640-731	8.02-8.90
Below average	809-879	10.96-11.64	595-639	7.58-8.01
Fair	739-808	9.57-10.95	549-594	7.14-7.57
Poor	<739	<9.57	<549	<7.14

Reprinted by permission from Zupan, M. F., Arata, A. W., Dawson, L. H., Wile, A. L., Payn, T. L., & Hannon, M. E. (2009). Wingate anaerobic test peak power and anaerobic capacity classifications for men and women intercollegiate athletes. The Journal of Strength and Conditioning Research, 23(9), 2598-2604

Table 3.18 Wingate Anaerobic Test Classification of Peak Power (W, W/kg) and Anaerobic Capacity (W, W/kg) Among Women [65]

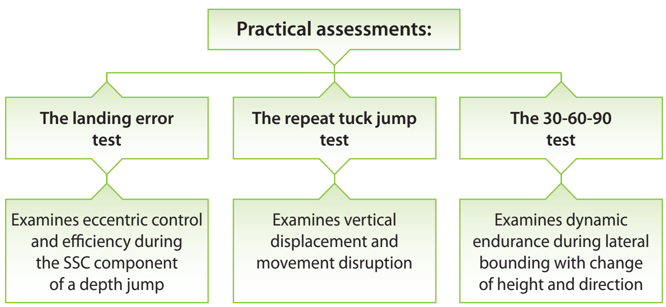
Categories	Peak Power (W^{-1})	Peak Power (W/kg)	Anaerobic Capacity (W)	Anaerobic Capacity (W/kg^{-1})
Elite	>730	>11.07	>541	>8.22
Excellent	686-730	10.58-11.07	510-541	7.51-7.85
Above average	642-685	10.08-10.57	478-509	7.51-7.85
Average	554-641	9.10-10.07	414-477	6.81-7.50
Below average	510-553	8.60-9.09	382-413	6.45-6.80
Fair	467-509	8.11-8.59	351-381	6.10-6.44
Poor	<467	<8.11	<351	<6.10

Reprinted by permission from Zupan, M. F., Arata, A. W., Dawson, L. H., Wile, A. L., Payn, T. L., & Hannon, M. E. (2009). Wingate anaerobic test peak power and anaerobic capacity classifications for men and women intercollegiate athletes. The Journal of Strength and Conditioning Research, 23(9), 2598-2604

Power-related Stability Tests

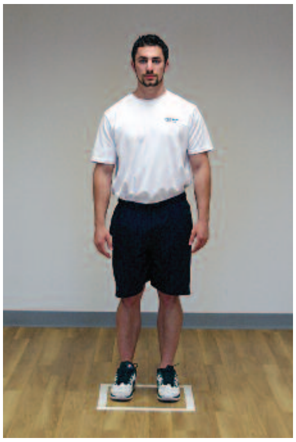
Power-related stability is also a key element in sports performance. Too often athletes are trained to be powerful but not to perform in a manner that harnesses their power in an optimized fashion. This is often demonstrated by a loss of power during repeated actions. Essentially, the power is there – the athlete just does not know how to manage it in an uncontrolled environment. In some cases, it is strength imbalances that contribute to the issue, in others it is a lack of experience in the environment; but most commonly it is poor kinetic (energy) transfer efficiency due to variability in motion segment stability. Three tests have been used to evaluate some of these potential issues. Performance in all three is compromised with central and/or peripheral instability under conditions of applied power.

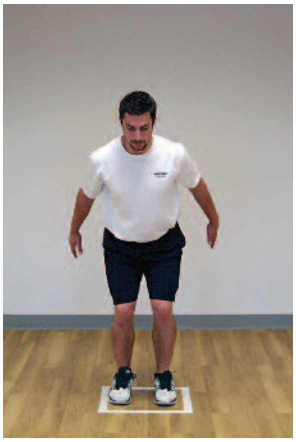
Figure 3.22 Power-related Stability Tests



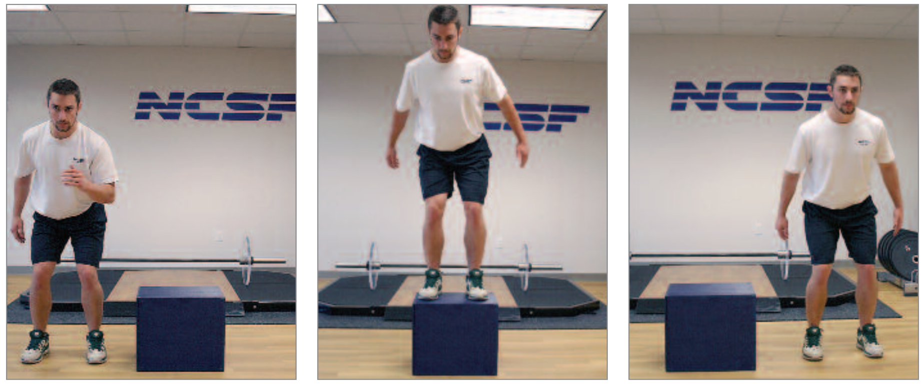
Repeat Tuck Jump Test

The repeat tuck jump test requires the athlete stands inside of a 18" x 18" square indicated by tape or paint. At the go command he or she performs as many tuck jumps as possible for 20 seconds. Each jump must start and end within the square and the knees must attain a hip-level height. The coach tallies the total number of jumps performed as well as the number or times the athlete lands outside of the square. The higher the number of jumps and the lower the number of errors (landing outside of the square), the greater the power-related stability. This data can be used for comparative purposes, but no normative data exists.





30-60-90 Test



The 30-60-90 test is useful for a number of reasons as it measures repeat jump ability, dynamic stability, and anaerobic capacity. In this test the athlete jumps laterally on and off a box as quickly as possible with both feet for 30 seconds. At the 30 second mark they immediately sit on the box for recovery as the tester records the number – at 25 seconds they stand and attain the ready position; they are signaled to start jumping again when the stopwatch hits 60 seconds. They then attempt a maximal number of jumps for 30 more seconds. At the 90 second mark the test is stopped. The number of contacts are again recorded and totaled with the first effort.

Protocol technique:

- The athlete begins standing adjacent to a 12" box (18" wide)
- He or she must repeat the following sequence for both 30-second efforts; attempting to perform as many hops as possible
    a. Lateral hop onto the box
    b. Lateral hop to the opposite side
    c. Lateral hop back onto the box
    d. Lateral hop back to the starting position

High-level athletes usually beat their initial score during the second round of jumps due to neural improvements. Low-level athletes will score poorly during both efforts, but tend to have a lower second number due to losses in efficiency and fatigue. Total hops demonstrate a measure of anaerobic capacity while any reduction in jumps between the first and second efforts indicates power-related inefficiency. An athlete who performs 20 total hops versus another who performs 35 has a lower power output capacity; while an athlete who performs 20 hops for the first sequence and 21 hops during the second has greater power-related stability than another athlete who first performs 20 hops and then can only repeat the sequence for 18. This test has no known normative data and is used for comparative data analysis over a defined training cycle.

Landing Error Test

The landing error test is used to identify biomechanical/movement pattern errors during tasks that require landing from a jump. It also examines stability during exploitation of the SSC, and can indicate an athlete's relative risk for injury during landings. The athlete begins by standing on a 12" box and a target line is drawn on the floor at a distance equal to half of the athlete's height. The athlete is instructed to jump forward off of the box so that they land with both feet just beyond the target line, and immediately upon landing, perform a vertical jump for maximum height. It is advised to allow the athlete to view a demonstration of the action and practice the movement before setting up video cameras (about 10 feet from the box) to collect data for biomechanical analysis. The athlete performs three depth jumps as just described while being filmed. The video content is evaluated based on the criteria in Figure 3.23.

Figure 3.23 Landing Error Scoring System

Video analysis scoring involves the following "yes or no" questions
Higher score = greater risk for injury

- Knee flexion at initial contact >30° *(Yes = 0, No = 1)*
- Knee valgus at initial contact – knees over midfoot *(Yes = 0, No = 1)*
- Trunk flexion at initial contact *(Yes = 0, No = 1)*
- Lateral trunk flexion at initial contact *(No = 0, Yes = 1)*
- Ankle plantar flexion at initial contact – toe to heel contact *(Yes = 0, No = 1)*
- Foot position at initial contact – toes externally rotated >30° *(No = 0, Yes = 1)*
- Foot position at initial contact – toes internally rotated >30° *(No = 0, Yes = 1)*
- Stance width at initial contact, less than shoulder width *(No = 0, Yes = 1)*
- Stance width at initial contact, greater than shoulder width *(No = 0, Yes = 1)*
- Initial foot contact symmetrical *(No = 0, Yes = 1)*
- Knee flexion displacement >45° *(Yes = 0, No = 1)*
- Knee valgus displacement – knee inside big toe *(No = 0, Yes = 1)*
- Trunk flexion at maximum knee angle – trunk flexed more than at initial contact *(Yes = 0, No = 1)*
- Hip flexion angle at initial contact – hips flexed *(Yes = 0, No = 1)*
- Hip flexion at max knee angle – hips flexed more than at initial contact *(Yes = 0, No = 1)*
- Joint displacement, sagittal plane *(Soft = 0, Average = 1, Stiff = 2)*
- Overall impression *(Excellent = 0, Average = 1, Poor = 2)*

Upper Body Power Assessments

Obtaining a power wattage estimate for the upper body is not easy outside of the laboratory. The only equation proposed for a field test requires the use of the 1RM bench press, but the related assessment may not be the best choice for most athletes.

Formula for test of upper body power using the bench press [67, 68]:

$$\textbf{Power} = \frac{\text{Bar mass in kg x 9.81 x bar distance in m}}{\text{seconds}}$$

Major issues with using a 1RM bench press and the above equation for assessing power:

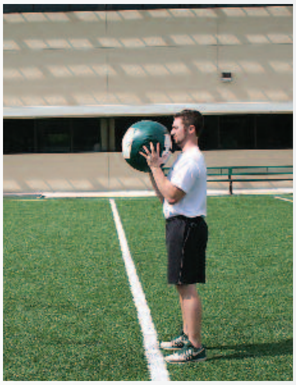
- It is a strength movement
- The load, grip width, and vertical distance must all be precisely controlled
- Variability in technique and scoring affect validity and reliability

So, while a calculation does exist for the bench press power test, it is likely better to use one or more of the available throwing tests for comparative data and to monitor upper body power development.

Medicine Ball Put Test

The medicine ball put test is a useful throw test because the 45° incline bench facilitates an optimal load trajectory. In other words, it minimizes the effect of throw angle variance on the final distance and helps with reliability between tests. The medicine ball load for athletes is 9 kg for males and 6 kg for females. The athletes should be allowed to execute 2 practice throws with a full recovery between throws. The bench should be anchored to the ground and a measuring tape should be extended directly forward from the bench to a distance of 10 m. A 0.6 m (2 feet) border should be established on each side of the measuring tape to show the athlete the valid throw area [68]. If the throw lands outside the permitted area, the distance is not counted and the athlete should rest 2 minutes before the next attempt. Legal throws (within the permitted area) should be measured to the nearest inch (2.54 cm) [68].

Horizontal Chest Throw



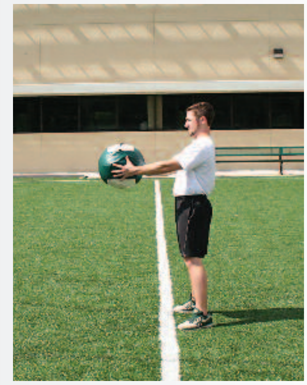
Medicine Ball Horizontal Chest Throw and Forward Power Throw Tests

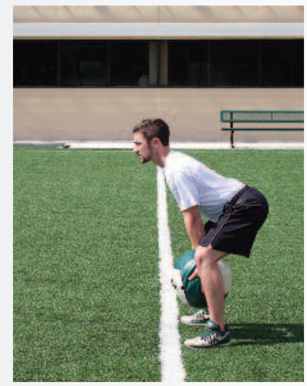
Two additional upper body field tests that can be used to assess relative power are the medicine ball horizontal chest throw and the forward power throw. The horizontal chest throw allows for two different techniques; a standing start with a countermovement jump, or a kneeling start with countermovement hip flexion. The standing horizontal chest throw conceptually emulates a push press but requires a horizontal throwing trajectory. The athlete will start by standing at a marked line with their feet under their hips holding a medicine ball (12 lbs males, 6 lbs females). They will attempt to throw the ball as far forward as possible in a single effort. While the athlete may jump they cannot cross the line, nor can they throw the ball using a single-sided dominant push (no bilateral asymmetry). Similar to the medicine ball put test, the athlete performs two practice throws with full recovery between efforts before being measured. The distance is also measured using the same technique as the medicine ball put test. The kneeling horizontal chest throw functions in the same manner, only the athlete starts in a kneeling position rather than standing. They are allowed to flex the hips in a countermovement action to maximally throw the ball; however, they are not allowed to fall forward upon the throw.

The forward power throw also combines upper and lower body actions, but measures power efficiency across joints to a greater degree. Athletes are required to use a countermovement underarm throw using maximal hip extension to throw the medicine ball the furthest horizontal distance possible. The action looks like a squat swing, which significantly challenges total kinetic chain connectivity. Unlike the backward overhead medicine ball throw (BOMB) which increases the risk of back hyperextension, the forward power throw places much more emphasis on the hips. The athlete stands at the start line in a shoulder-width stance holding a medicine ball (12 lbs male, 6 lbs female) at chest height using a symmetrical neutral grip. The wider stance is used to allow the ball to swing between the legs during the countermovement prior to the throw. Following a practice round of two throws with full recovery, the athlete is allowed three attempts to throw the ball as far as possible.

When measuring the distance a spotter should stand 5 m lateral of the throwing lane. When the medicine ball lands they should immediately mark the site with a flag marker. The distance should be measured while the athlete recovers as the marker may be hit in subsequent throws. Throwing activities can be dangerous so spotters must clear the area and announce when it is safe to throw the medicine ball. Additionally, with any tests using multi-effort directional displacement, adding afferent data can provide greater results. Therefore, using marks from prior attempts aid the athlete in attempting to beat the throw distance. This strategy works well to help maximize effort during all throws as well as vertical and horizontal jumps.

Forward Power Throw





Speed Testing

Speed is arguably the greatest athletic asset to sports performance at the elite level. Therefore, it should be considered paramount for any athletic development program. The distance covered and environments for testing should be matched to sport distances that dictate competitive outcomes. For instance, in American football and soccer the ability to run the length of the field is not as relevant as acceleration and speed covering shorter distances; which differs from basketball and tennis due to the size of the playing area and game tactics. Likewise, the relevance of 10 m run speed, often referred to as quickness, is more important for tactical set-ups than the ability to run 20 m; which is often more relevant to defense. A range of 5-100 m sprint distances have been used to test speed among varied sport athletes. The important consideration for coaches based on the aforementioned is to distinguish and separate maximal lower body running power, acceleration, and maximum speed. Lower body (running) maximal power is usually measured using a 5 m sprint distance. In fact, 5 m sprint and CMJ performance have been shown to have important correlations [69].

Even though running power effects acceleration, they are not the same thing. Acceleration is usually measured using distances between 10-30 m [70, 71]. The selection of the actual distance will be based on sport-specific speed requirements. The testing protocol most commonly used for any of these distances was proposed by Field (1989) and is presented in Figure 3.24.

Figure 3.24

Protocol for short-distance (10-30 m) running acceleration speed test:

- The athlete starts in a staggered stance position
- No command is given; the watch is started when the athlete's trailing foot contacts the ground in front of the starting line - or sets off the motion sensor
- The watch is stopped when the athlete's torso crosses the finish line
- The athlete must be instructed to go "all-out" from the start
- For best results, two athletes of nearly-equal ability should run together and be timed simultaneously using two watches (motivation via competition)

Maximum speed is often measured using the 30 m sprint with a 20-m flying start. This allows for measurement of a full 30-m sprint at maximum speed due to the initial period of untimed acceleration. The Field (1989) protocol for this type of assessment is presented in Figure 3.25.

Figure 3.25

Protocol for maximum speed test:

- Mark off a 20-m flying start zone that will connect with a 30-m sprint zone
- Have the participating athlete stand at the beginning of the 20-m flying start zone
- If not using motion sensor devices - One coach will stand at the end of 20-m start zone with an upraised hand; this individual will drop his or her arm when the participating athlete's torso reaches the starting line
- Start the watch when the helper's hand is dropped; stop the watch when the participating athlete's torso crosses the finish line of the 30-m sprint zone
- Instruct the participating athlete to be at max speed when entering the 30-m sprint zone
- For best results, two athletes of nearly-equal ability should run together and be timed simultaneously using two watches (motivation via competition)

It is important to understand that acceleration and maximum speed are independent variables that should be tested separately. When 106 professional soccer players were tested using the aforementioned protocols (10 m sprint distance and a modified 30 m run with a 20-m flying start) the analyses of the results showed that acceleration and maximum speed were independent attributes [70]. Furthermore, COD capacity was also found to be independent of acceleration and maximal speed. This suggests that athletes should be assessed for each separately, and training protocols should be applied independently in the conditioning program to ensure proper adaptation specificity.

Positional applications are also relevant and may add to the data collection process. American football presents a great example of this as different positions have varying starting postures, and some actions are initiated from a static position whereas others begin from a running start. Defensive backs for instance, start backwards or may face diagonally, whereas receivers start facing forward. Positional variations also determine the need for maximal acceleration from a run as a key element to defense and turnover in many sports. Interestingly, the static start 40-yd dash is the common speed assessment tool used across all positions in American football, but this may not present the best information for sport-specific programming. Decisions regarding total distance, starting position, and whether the assessment is measuring acceleration or maximal speed are all important when selecting an optimal speed test for a sport, and by position.

Agility and Change of Direction (COD) Capacity Testing

Agility will be discussed in greater detail later in the text, but for the purposes of testing it is important to recognize agility always requires a component of reaction. Therefore, agility assessments must account for measures of the athlete's physical capacity to rapidly and efficiently change directions as well as their cognitive capacity to react to changes in the environment. In other words, there is a significant difference between executing lane agility drills in a basketball combine (after it has been practiced and rehearsed repeatedly) and having to react to an opponent's crossover move during a game. Testing COD using rehearsed movement patterns should be considered different from assessing reaction-based movement abilities. This relates to the difference between what are called open and closed skills. **Open skills** are those involving changing environments where the athlete has to move in reaction to these changes; as examples, a boxer evading punches thrown by the opponent or a soccer player chasing the opponent-controlled ball. **Closed skills** refer to those movements that may be performed under a constant environment like bowling where the pins don't move and the lane is consistent.

For the most part, sports have some degree of both components. For example, basketball which is mostly open-skilled in nature has the free throw (closed skill) as an important component of the game. However, sports are predominantly one or the other, and generally sports that require proficiency in agility are primarily open-skill dominant. Therefore, when testing athletes for COD, coaches should use both closed- and open-skilled conditions. Likewise it is recommended to consider sport specificity to assess an athlete's ability to change directions at high speeds in game-like environments.

The rationale behind testing validity for sports performance using open skill assessments has been well supported in the literature. In one study, a group of elite netball players were tested for COD using both open- and closed-skill conditions. The open-skilled condition required them to respond to a digital image of an offensive player's movements prior to passing a ball either to the right or left side. The closed-skilled condition employed the same movement pattern using cones and a pre-planned right or left turn[72]. Not surprisingly, the "highly-skilled" players were able to conduct the open-skill test faster than the lower-skilled players. However, the better players were not able to outperform the lower-skilled players during the planned cone test, even though it required a similar movement pattern [72]. Similar results have been found when analyzing reactive and planned COD activities among rugby league players of different skill levels [73, 74].

Essentially, open-skilled, reactive COD tests are often better predictors of skill and playing level than traditional pre-planned "agility drills". In any case, coaches should test athletes under both conditions and select assessments that best reflect the position played. Testing should not only be sport-specific but also position-specific whenever applicable. Position-specific agility test protocols for soccer are provided in the following section:

The sprint 9-3-6-3-9 m with backward and forward running (SBF) test, the sprint 9-3-6-3-9 m with 180° turns (S180°) test, the sprint 4 x 5 m (S4 x 5) test, and the traditional T-test (TT) have been shown to be very reliable in predicting COD proficiency among soccer players as well as selecting talent [75].

Due to the different movement patterns required of each position during soccer:

- Defenders are best assessed using the TT test
- Midfielders are best assessed using the SBF and/or the S180° test
- Forwards are best assessed using the S4 x 5 test

TT test: The athlete starts with both of the feet behind cone A. After the signal, he or she must sprint 9.14 m forward and touch cone B, shuffle 4.57 m to the left and touch cone C, shuffle 9.14 m to the right and touch cone D, shuffle 4.57 m to the left back to cone B and finally backpedal past the finish line through cone A.

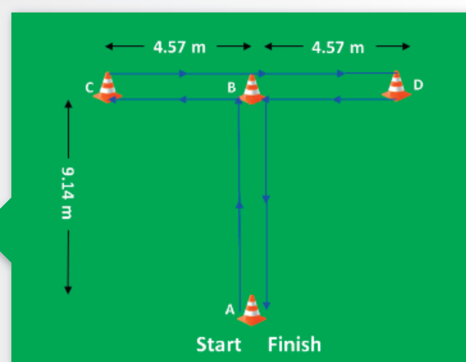
DEFINITIONS

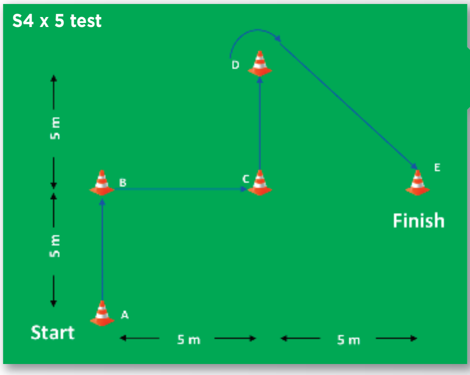
Open skill –

Skills performed in a changing environment that forces the athlete to react to external stimuli (e.g., dodging punches while boxing)

Closed skill –

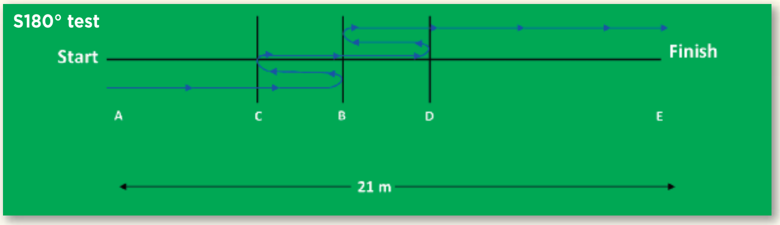
Skilled movements that are often performed under a constant environment (e.g., hitting pins while bowling)



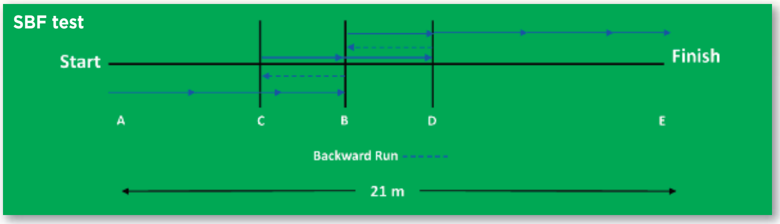


S4 x 5 test: Five cones are set up as seen in the figure to the left. The athlete starts in a ready position at cone A. After the signal, he or she must run 5 m from cone A to cone B; at cone B, shuffle 5 m to cone C; at cone C, run to cone D; make a 180° turn around cone D and sprint to cone E to finish the movement pattern.

S180° test: The athlete starts at line A. After the signal, he or she runs 9 m to line B (lines are drawn white, 3 m long and 5 cm wide). The athlete touches line B with one foot, turns and runs 3 m back to line C, turns again, and runs 6 m to line D. From here the athlete will turn again and run 3 m back to line B before making a final turn and running the final 9 m to finish at line E.



SBF test: The distance covered is equal to the S180° test. The only difference is the athlete shifts from forward to backward running rather than making turns. After the signal, the athlete first runs forward 9 m to line B. Having touched line B with one foot, the athlete runs backwards 3 m to line C, runs forward 6 m to line D, and then backward 3 m again to line B before finally running forward 9 m to finish at line E.



There are a number of "agility" tests that have been historically employed across many sports. However, there are two potential issues with these classic agility tests; 1) they are premeditated, closed-skill assessments, and 2) they have not been scientifically validated for agility. This may make them more useful for comparative rather than predictive data. Essentially, it is not clear if these assessments are actually good predictors of an athlete's agility and COD skills; however, coaches might still consider using some of these activities for data analysis. If for nothing else, these drills are often used in combines for recruitment tools and player comparisons, so becoming proficient in the movements may help an athlete's career. Also, for the coach there is abundant data in terms of the performance comparisons at different levels to gauge an athlete's playing-level readiness or aptitude. Some common drills include the 5-10-5 (pro agility), 3-cone L-drill, and 60-yard shuttle. When using these drills for testing or conditioning it is important to provide clear instructions on each aspect of the test. This includes explaining the start position and finishing requirements for reliability. Changes in starts and errors performing the test such as not touching cones, cutting inside rather than outside a marker, or not running through the finish point can all affect the score and force a repeat of the test. From a safety perspective, ensure the environment is conducive to the tests, especially high-speed running room for deceleration. Make sure multiple test areas do not overlap in a manner that two athletes could collide. Being well organized and having control over the environment always aids in quality data collection.

5-10-5 (Pro agility)

Purpose

Used to assess COD capacity involving linear sprints and lateral mobility

Procedures

The athlete straddles the center cone using a 3-point stance, with the down hand in contact with the center line. Upon an auditory signal, the athlete sprints 5 yds to the cone on the left, sprints 10 yds to the cone on the right, and then sprints 5 yds back past the center cone. The athlete must contact each of the end cones with their hand.

Technique checkpoints

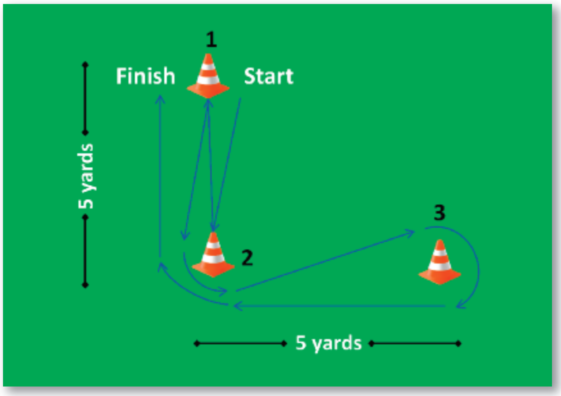
- As the athlete approaches each cone, the outside leg is planted to facilitate the most rapid transition in movement direction

Table 3.19 Percentile Ranks for the 5-10-5 (Pro agility) Among NCAA Division I College Athletes [59]

% rank	Women's volleyball	Women's basketball	Women's softball	Men's basketball	Men's baseball	Men's football
90	4.75	4.65	4.88	4.22	4.25	4.21
80	4.84	4.82	4.96	4.29	4.36	4.31
70	4.91	4.86	5.03	4.35	4.41	4.38
60	4.98	4.94	5.10	4.39	4.46	4.44
50	5.01	5.06	5.17	4.41	4.50	4.52
40	5.08	5.10	5.24	4.44	4.55	4.59
30	5.17	5.14	5.33	4.48	4.61	4.66
20	5.23	5.23	5.40	4.51	4.69	4.76
10	5.32	5.36	5.55	4.61	4.76	4.89
$\bar{x}$	5.03	5.02	5.19	4.41	4.53	4.54
SD	0.20	0.26	0.26	0.18	0.23	0.27
n	81	128	118	97	165	869
$\bar{x}$ = mean						

Reprinted by permission from Hoffman, Jay. Norms for fitness, performance, and health. Human Kinetics, 2006.

3-cone L-drill



Purpose

Used to assess COD proficiency, general quickness, looping turn ability, and bodily control

Procedures

Three cones are placed in an L-pattern, spaced 5 yds apart from each other. The athlete starts in a 2- or 3-point stance next to cone 1. On a verbal command he or she (1) sprints to cone 2 and touches it with their right hand, (2) sprints back to cone 1 and touches it with their right hand, (3) runs back around cone 2, (4) weaves inside cone 3, and (5) finally sprints around cones 3 and 2 to return back to the starting position. Use of this as a COD assessment is best when the drill is performed in both directions (left and right positions for cone 3).

Technique checkpoints

- The athlete must continue running at all times during this drill, rather than pivot, if it is used as an assessment to compare results to normative data

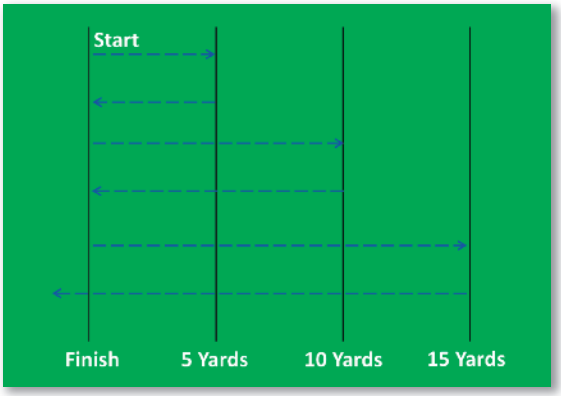
Table 3.20 5-10-5 (Pro agility) and 3-cone L-drill Performance for College Football Players Participating in the NFL Combine

	Pro Agility (sec)								3- Cone (sec)							
% rank	DL	LB	DB	OL	QB	RB	TE	WR	DL	LB	DB	OL	QB	RB	TE	WR
90	4.22	4.07	3.89	4.45	4.07	4.02	4.18	3.97	7.22	7.05	6.87	7.66	7.06	7.17	7.12	6.85
80	4.32	4.13	3.96	4.53	4.12	4.14	4.21	4.03	7.45	7.16	6.97	7.82	7.13	7.29	7.16	7.01
70	4.38	4.16	4.05	4.57	4.16	4.18	4.26	4.07	7.52	7.30	7.07	7.98	7.19	7.32	7.27	7.10
60	4.41	4.21	4.07	4.61	4.20	4.22	4.31	4.10	7.64	7.38	7.09	8.07	7.31	7.36	7.38	7.19
50	4.46	4.24	4.12	4.69	4.25	4.25	4.35	4.15	7.71	7.49	7.14	8.15	7.36	7.47	7.42	7.28
40	4.52	4.28	4.18	4.77	4.33	4.31	4.39	4.20	7.78	7.54	7.22	8.28	7.40	7.53	7.48	7.35
30	4.58	4.31	4.19	4.83	4.36	4.34	4.42	4.24	7.89	7.61	7.29	8.38	7.54	7.60	7.57	7.41
20	4.68	4.41	4.21	4.93	4.38	4.38	4.46	4.26	8.07	7.70	7.39	8.51	7.59	7.71	7.71	7.49
10	4.75	4.53	4.27	5.06	4.41	4.49	4.56	4.33	8.47	7.84	7.47	8.66	7.70	7.82	8.04	7.58
$\bar{x}$	4.48	4.26	4.11	4.74	4.26	4.26	4.35	4.15	7.75	7.45	7.17	8.18	7.29	7.48	7.47	7.26
SD	0.22	0.17	0.15	0.39	0.15	0.16	0.13	0.15	0.43	0.30	0.22	0.43	0.57	0.27	0.34	0.30
n	89	38	76	125	38	58	39	85	88	57	102	139	38	58	41	86

DL = defensive linemen, LB = linebackers, DB = defensive backs, OL = offensive linemen, QB = quarterbacks, RB = running backs, TE = tight ends, WR = wide receivers; $\bar{x}$ = mean

Reprinted by permission from Hoffman, Jay. Norms for fitness, performance, and health. Human Kinetics, 2006

60-yd shuttle



Purpose

Used to assess COD efficiency and linear movement transitions

Procedures

The athlete begins in a 2- or 3-point stance (record stance position) in front of a designated line. Three cones (or lines) are placed 5, 10, and 15 yds away from the start position in a straight line. The athlete must sprint to each cone (beginning with the closest cone), touch the ground, and run back to the start line to touch the ground before moving to the next cone in consecutive order. The test ends with a sprint past the starting position. The drill requires five CODs and ground coverage equaling 60 yds.

Technique checkpoints

- The linear movement transitions should be facilitated with efficient planting and pivoting to cover the distance as quickly as possible

There is limited historical data available for this test but the following table presents the top 10 NFL combine times for 2008-2014 [76].

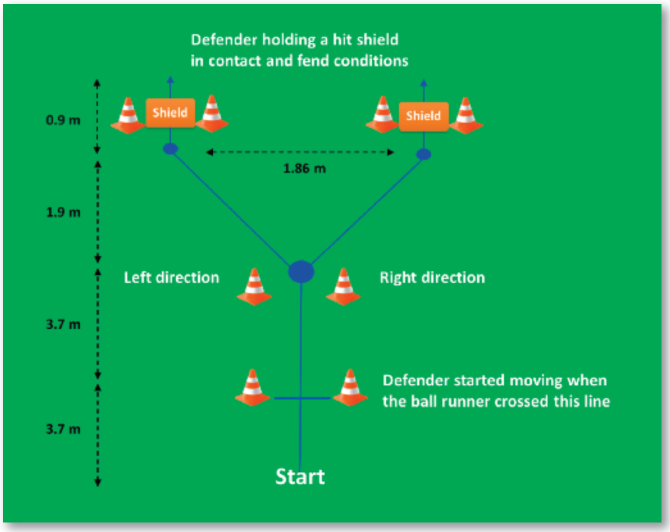
Table 3.21

Rank	Time (sec)	Name	Year
1	10.72	Cooks, Brandin	2014
2	10.75	Fleming, Jamell	2012
3	10.75	Skrine, Buster	2011
4	10.80	Sorensen, Daniel	2014
5	10.84	Copeland, Damian	2014
6	10.87	Cortez, Allen	2011
7	10.87	Moe, T. J.	2013
8	10.87	Shields, Arman	2008
9	10.88	Maehl, Jeffrey	2011
10	10.92	Hartline, Brian	2009

Developing a Sport-Specific Testing Battery for COD Proficiency and Agility

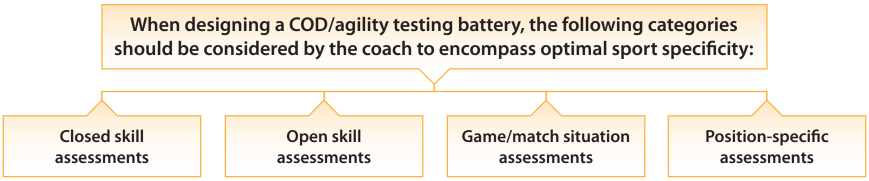
When developing a battery of tests for agility and COD capacity, the coach must consider how to make traditional assessments or movement patterns as sport-specific as possible. This usually requires using a sports implement (such as a ball) and game-specific actions, when applicable. Even though these tests may be more difficult and sometimes time-consuming to execute, they often provide important information about the athlete. An example of this type of test was recently used to assess elite rugby players. Agility was evaluated using a game imitation obstacle course (Figure 3.26) that included evading a defender and hitting a training shield while carrying a ball at top speed [77]. The idea behind these types of tests is that environmental situations compel changes that cannot be accounted for during traditional COD assessments. Researchers found the addition of sport actions changed the athlete's running technique during the drill in a manner that could not be accounted for without the use of the specific match-play situations [77]. This has been consistently demonstrated when game-like situations are added to sport movements.

Figure 3.26 Assessment for Rugby Players Including Sport-Specific Implement, Environment and Skill Execution [77]



Reprinted by permission from Wheeler, K. W., & Sayers, M. G. L. (2011) Rugby union contact skills alter evasive agility performance during attacking ball carries. International Journal of Sports Science and Coaching, 6(3), 419-432.

Figure 3.27



Balance Testing

Balance refers to an athlete's ability to maintain or control the position of their body relative to static or dynamic conditions. Physics suggests this requires voluntary maintenance of the individual's center of gravity over their base of support. This ability depends on coordinating and rapidly executing neuromuscular movements in response to sensory information[78]. Balance is important not only in terms of predicting performance, but also in terms of injury prevention; suggesting coaches consider including balance assessment as part of a comprehensive battery of tests. As mentioned in Chapter 1 there are two types of balance: static balance reflects the ability to maintain equilibrium, where the sum of all forces equal zero causing no movement, while dynamic balance includes the ability to regain a stable position at the end of a movement, maintain control when moving, and attenuate the loss of balance under unstable conditions while completing a task. Therefore, coaches should test athletes under both conditions and consider the demands of the sport and relevance of unilateral versus bilateral assessments.

Most sports require contributions from both static and dynamic balance due to the nature of open- and closed-skill activities. Therefore, coaches should match testing conditions to the sport and understand how the outcomes actually relate to performance. Consider the balance requirements of two very different sports – soccer and swimming. Elite soccer players and swimmers were tested under a two-legged dynamic ground-based condition, yet both performed similarly despite an apparent advantage for soccer players considering they actually perform their sport on land [79]. However, due to the fact that soccer players need to support their body on one leg when kicking a ball, they clearly need (and have) superior one-legged balance when compared with swimmers and athletes in other sports [80]. For this reason a strength coach may test a soccer player using a unilateral dynamic balance test, but use a bilateral dynamic balance test to assess a football lineman. In other cases such as basketball, both are relevant and often predictive. Those athletes with repeat ankle rolls for instance, demonstrate disparities in unilateral balance, lacking static control on the high risk side.

In some cases, sport-specific skills and the playing level of the athlete require detailed attention to make finite adjustments in maximal performance. For example, most golfers have great two-legged dynamic balance since it is an essential component of a swing and necessary for putting. However, the highest-level golfers are statistically differentiated when tested under the single-legged static conditions [81]. Essentially, elite golfers maintain two-legged dynamic balance consistent with their peers, but also possess distinct additional balance capabilities that separate them on the course. As it turns out, the additional performance in the apparently "non-sport-specific" condition actually helps them manage weight shifts during regular swings as well as uncommon shots that often make a difference in winning versus losing; such as an uphill or downhill shot or when awkwardly positioned in a sand trap [81].

There are a number of laboratory tests that can be used to assess an athlete's balance. Most use clinical equipment such as force plates and motion platforms (e.g., Proprio 5000 and the Biodex Balance System). Field tests can also be used but many of them are designed for testing the general population, and therefore fail to provide predictable data when used among higher-level athletes. For example, elite athletes may be able to spend minutes maintaining equilibrium when performing the single-leg stance test (eyes open) or easily negotiate the side-step test or tandem walking test. With these tests athletes would score very high marks but not be differentiated by performance when compared to similar-level competitors.

Static Balance – Balance Error Scoring System (BESS) Test

The balance error scoring system (BESS) has been used successfully among athletes [82] and is known to be reliable for evaluating static balance [83]. The BESS requires an athlete to execute a battery of three balance stances on varying surfaces with their eyes closed. The closed-eye component of the tests elicits a greater response from proprioceptors compared to open-eye balance assessments. The testing battery includes the double-leg stance, the single-leg stance, and the tandem stance with one foot directly behind the other (heel to toe contact). During all stances the athlete's hands must remain on their hips at the iliac crests, and their feet must remain together during tandem stance tests. The athlete is instructed to hold each stance for 20 seconds. Scoring is based on the number of errors executed during this time (Figure 3.28). All three stances are conducted first on a firm surface and then on an unstable surface (foam pad) for a total of six assessments. At the end of the six trials, the total number of errors from each stance is added to obtain the total BESS score [82, 83].

Figure 3.28

BESS assessment errors:

- Opening the eyes
- Removing the hands from the hips to balance
- Stepping, stumbling, falling or otherwise losing the stance position
- Remaining out of the test position for 5 sec
- Lifting the forefoot or heel
- Abducting or flexing the hip by >30°

Stances used during the BESS:

Double-leg stance

Single-leg stance

Tandem stance

Double-leg stance on foam pad

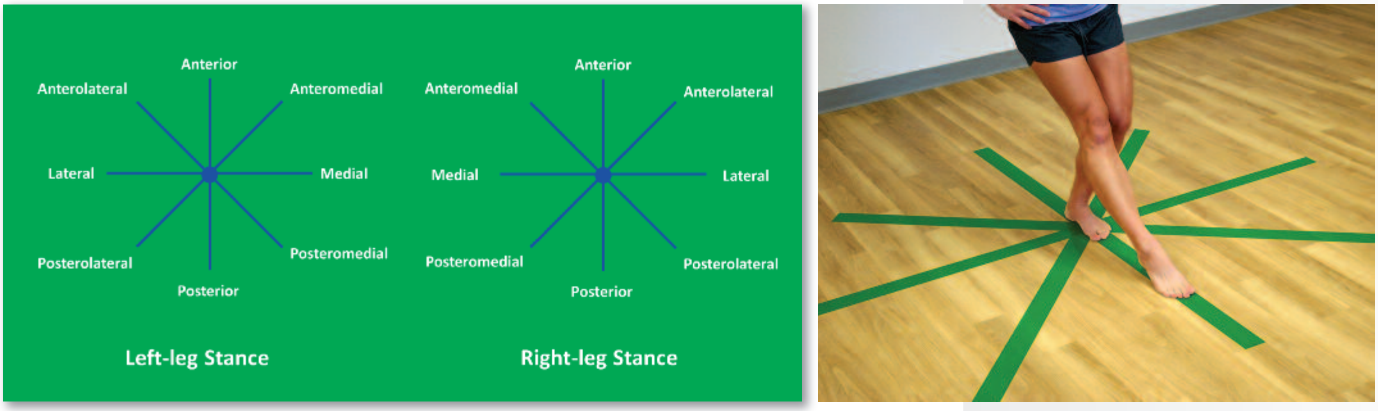
Single-leg stance on foam pad

Tandem stance on foam pad

Dynamic Balance – Star Excursion Balance Test (SEBT)

When looking at dynamic balance, the star excursion balance test (SEBT) is a practical tool that can be easily implemented by coaches as described by Gribble & Hertel (2003). It has also been used with the BESS to assess both static and dynamic balance to predict overall balance capacity [82]. The SEBT requires the athlete to stand on one leg in the middle of a grid formed by eight lines extending out at 45° from each other as seen in Figure 3.29.

Figure 3.29 Single-leg Reaching Patterns during the SEBT



The athlete starts with a single-support leg in the center of the star and reaches as far as possible along each of the eight lines with the non-support leg to touch a line or mark on the floor with the toes. The tap touch is preferably done with the hallux (big toe). When executing the lateral and posterolateral directions, the athlete must reach by crossing behind the support leg. Coaches should allow the athlete to practice reaching in each of the eight directions a total of six times so that they are proficient in the actions before executing the trial [84, 85].

SEBT protocol:

- Practice each reach 6x before the initial trial
- Rest 5 minutes
- Perform the test 3x on the dominant leg
  - The athlete should always start with the dominant leg so the coach can evaluate improvements under the same conditions
- Rest 5 minutes
- Perform the test 3x using the non-dominant leg
- Record the best reach of each movement (16 measurements in total); being the distance from the center of the grid to the point of maximum reach by the hallux
- Reaching scores are directly correlated with leg length; therefore, these values are often normalized to the athlete's leg length as measured from the anterior superior iliac spine (ASIS) to the medial malleolus

Note: It is important that the coach carefully evaluates the performance. If he/she sees that the athlete uses too much support time, takes too long between reaches (indicating a shift towards static balance), moves the foot from the center of the grid, is unable to return the foot to the starting position, and/or losses balance on the stance leg – the test must be repeated and the result should be discarded [84].

Even though the SEBT has been criticized because it may be affected by flexibility, coordination or power, an athlete's balance will be affected by these factors during competition making them important contributors to sport-specific assessment. Certainly, isolation aids in identification of weaknesses, but performance is best assessed by using conditions an athlete will experience during competition. It should be also noted that the SEBT appears to identify a number of lower-extremity injuries according to the literature.

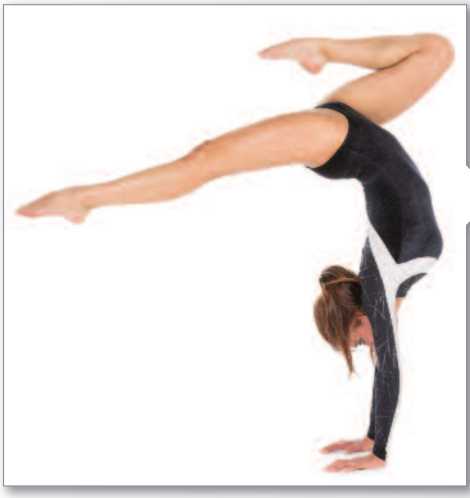
Table 3.22 Combined Balance Assessment Scores for Female Athletes from Soccer, Basketball, and Gymnastics [82]

Sport	BESS Static Balance Unitless Error	SEBT Dynamic Balance ∑ % of Leg Length
Soccer		
Dominant limb	13.3 ± 1.3	756 ± 16.1
Nondominant limb	11.6 ± 1.4	756 ± 13.6
Mean	12.5 ± 1.1	756 ± 14.0 †
Basketball		
Dominant limb	13.6 ± 1.1	694 ± 16.1
Nondominant limb	14.5 ± 1.4	714 ± 13.6
Mean	14.1 ± 1.1	704 ± 14.0
Gymnastics		
Dominant limb	8.8 ± 1.1	731 ± 15.4
Nondominant limb	9.3 ± 1.3	739 ± 13.0
Mean	9.1 ± 1.1 ‡	735 ± 13.4

† Significantly greater than basketball group, P = .04.
‡ Significantly less than basketball group, P = .01.
∑% of Leg Length is computed by dividing each of the 8 leg-reach distances by the athlete's leg length to find % of Leg Length, and finding the sum of the percentages

While there is very limited normative data to compare balance tests, strength coaches can use scores to concentrate on sport-specific requirements/development (e.g., a soccer player's single-leg dynamic balance requirements for kicking), player selection and performance prediction (e.g., balance has been shown to improve ice hockey maximum skating speed and luge starts) [78]. More importantly, coaches can use assessment data to individualize balance training requirements or increase programmatic emphasis for a team. Among less-proficient athletes, balance training has been shown to improve vertical jumping ability, agility, and overall performance. This may lend itself to exercise selections that provide more balance-related challenge (closed chain and/or unilateral) over activities where it is not as emphasized.

Among elite athletes sport-specific balance training seems to provide improvements. For example, a simple two-week training program requiring skiers to balance themselves on a balance board with and without poles wearing ski boots for 20 minutes resulted in better downhill slalom scores [86]. It is believed that sport-specific balance training may create neuromuscular changes at the spinal and supraspinal levels that limit the stretch reflex; plausibly increasing the speed of force generation and power output [78].



Coordination Testing

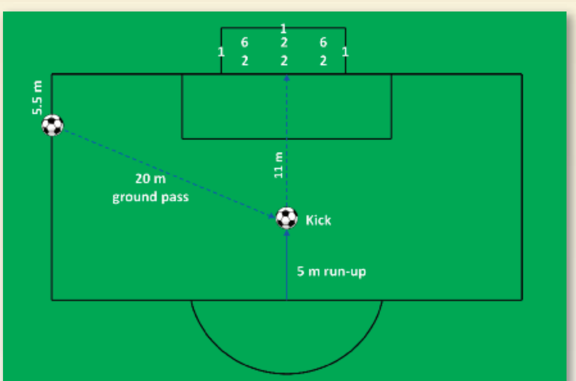
As mentioned in Chapter 1, coordination is likely the most complicated of the PRCF due to its genetic-derived characteristics. Therefore, it is not only one of the most difficult performance components to develop, but it is also one of the hardest to test. Earlier it was defined as the "intelligence" of peripheral nervous system (PNS) musculature and its ability to communicate efficiently with central processing (CNS). More specifically, it relates to the formation of "structural units" that work together towards the effective execution of a particular movement [87, 88]. The term structural unit is used because even though muscle synergies (or the capacity of muscles to work together) are part of coordination, they depend on motor centers in the brain and specific nerve patterns for movement while responding to the environment [87].

For example, when an athlete jumps, the gastrocnemius coordinates with the knee extensors to transfer energy in a phasic manner to optimize the timing of activation across both groups to maximize force [89]. If the muscle actions are uncoordinated, the knee extension component will be limited in its capacity to help lift the athlete off of the ground [89, 90]. The brain centers and nerve patterns not only activate the muscles but harmonize how they are activated. This identifies that a vertical jump is not only a power test but relies on coordinated neural patterns [90].

For this reason coordination is a difficult variable to isolate for training and/or testing. It would appear that in order to be sport-specific, a coach would have to replicate all movement patterns in a given sport. However, training and testing coordination can be broken down into more basic movements (e.g., jumping) so the fitness component can be properly managed. For instance, a clean pull from the floor is better at increasing power compared to a deadlift followed by plantar flexion action due to the coordination between movements involved during "triple extension" [90]. In other words, sport-specific "structural units" should be identified and tested in the same coordinated manner they exist in sport competition.

Rather than using a general coordination test, it is more likely that a strength coach will opt to select the movement or skills that require the greatest degree of coordination. For example, kicking a soccer ball when the ball is moving requires greater coordination than when it is stationary (Figure 3.30). As a matter of fact, the difference in accuracy between higher-skilled and lower-skilled soccer players at an elite level is significant. Elite, top-level players consistently outperform lower-skilled players when kicking a moving ball compared to kicking a stationary ball [91]. COD with reaction to a sport component is the easiest way to discern relevant coordination as it includes numerous harmonizing factors to be successful.

Figure 3.30



Shooting From a Pass Test Protocol [92]**:**

- A player takes 5 shots from a 20-m pass, using a 5 m run-up
- The ball is passed from the penalty area line using the goalkeeper's box as a guide at the official 11 m distance from the goal
- Scoring is tallied as follows:
  - 6 points - the shot enters the top right or left side areas of the goal
  - 2 points - the ball enters the goal from the top middle or any of the three lower sections
  - 1 point - the ball hits the crossbar or a goalpost
  - 0 points - the ball is kicked outside of the goal
- The final score is the sum of the five shots

Hand-eye coordination is also a neuromuscular skill which requires the synergistic actions of visual and motor functions. Afferent data collected from the environment must be translated into neural signaling for the required movement. It is particulalry important for sports which require the use of striking implements such as a racquet or bat, during upper-body intense sports such as boxing, and team sport actions such as blocking shots or catching a fast-moving ball. However, based on a review of literature, there does not seem to be any validated field tests for hand-eye coordination. Current testing for hand-eye cordination is usually conducted using computer-based programs, but light boards and related instruments are becoming more popular as technology reaches the field.

Hand-eye coordination can be improved similarly to other skills with practice. A group of table tennis players trained visual and hand-eye coordination three days per week for a total eight weeks in addition to their regular table tennis practice. The hand-eye coordination training was performed on a computer with each athlete holding two joysticks in either hand and tracing a ball on the screen along a path as fast as possible without touching virtual boundaries representing movement errors. The athletes who participated in this training improved their hand-eye coordination more than those who trained solely using the sport practice. Most relevant to the findings, was that the hand-eye coordination improvement transferred to discernible improvements in sport performance [93].

Sample Testing Program

As mentioned at the beginning of this chapter, the intention of this text was not to provide an exhaustive list of tests but rather to give coaches the tools to plan sport-specific testing batteries. Chapter 2 outlined consistent assessment protocols used in the sports analysis which may be considered useful for comparisons. A sample testing program for basketball has been provided for reference, but it will be up to each coach to make decisions in the best interest of their situation.

Based on the motion analysis data presented in Chapter 2, different fitness components exist for each of the positions in basketball (i.e., point guards, shooting guards/small forwards, and power power forwards/centers). Therefore, strength and conditioning programming should be designed by position. However, for testing purposes a basic battery can be constructed based on time/resource availability and the program strategy for the team. The first step is identifying the commonalities of the sport regardless of position, and identifying the key elements that matter the most. Anaerobic capacity seems to be the best predictor of playing level for all positions in basketball [94]. Other fitness components that are common to all positions include muscular power, speed, agility, and aerobic power [95]. Therefore, short-term anaerobic performance, speed at distances shorter than 28.65 m (length of the court), and explosive/reactive strength should be key factors addressed within the testing battery. Finally, the ability to sustain high-intensity efforts in a sport-specific situation has been shown to be another important predictor of playing level. Tests that incorporate dribbling the ball, shooting the ball, and running backwards without the ball can provide relevant data for sport-coordinated abilities [96].

The following testing battery is broken down into fitness assessments and sport-specific testing consistent with normative purposes in basketball [97]:

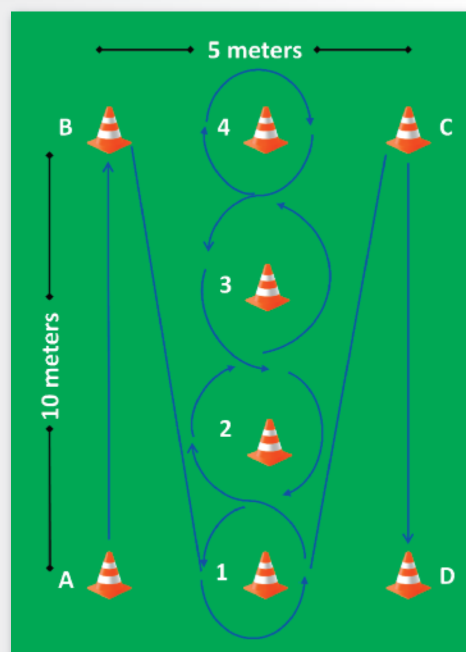
- **Fitness Component Assessments:**
  - Postural analysis and movement screen
  - Yo-Yo R1 – peak speed (km/h) and prediction of VO_2max
  - Sargeant jump test – calculates CMJ peak power (watts) and relative power (watts/kg)
  - Broad jump – power
  - Medicine ball put test – distance (m)
  - 5-m sprint (s), 10-m sprint (s), 30-m sprint (s) – similar to NBA Combine
  - Multi-rep bench press – related to NBA Combine
  - Multi-rep squat – predicted 1RM, related to NBA Combine
  - SEBT – dynamic balance
  - BESS – static balance
- **Sport-Specific Assessments:**
  - Illinois agility test
  - Lane agility drill

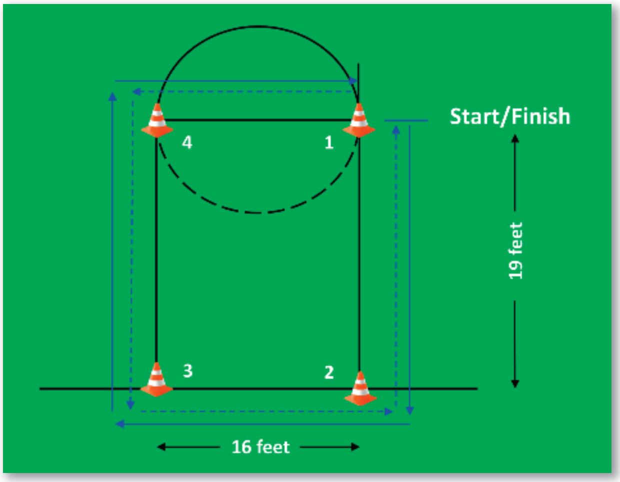
Sample Sport-Specific Assessment Protocol Descriptions

Illinois Agility Test

Procedures

- The coach needs eight cones
  - Four are set up to mark a rectangle 10 m (10.9 yds) long and 5 m (5.5 yds) wide
  - The other four cones dissect the rectangle 3 m apart
- The athlete starts in a prone push-up ready position with their head towards the start and the hands by their shoulders
- On the coach's command the stopwatch is started, and the athlete gets up as quickly as possible and runs around the course cones in a set direction to the finish line
- Total time is recorded
- The test is performed as follows:
  - The start and finish line is between cones A and D
  - From starting cone A, the athletes sprints to cone B; rounds the cone and sprints to cone 1
  - The athlete weaves through center cones 1-4, and then weaves back in the opposite direction returning to cone 1
  - From cone 1 the athlete sprints to cone C and back to cone D to finish





Lane Agility Drill

Procedures

- The coach sets up four (4) cones on the perimeter of the key (rectangle):
  - Two cones at the corners of the free throw line
  - Two cones at the corners of the key touching the baseline
- The test is performed as follows:
  - The athlete starts in the left corner of the free throw line facing the baseline at cone 1
  - On the coach's command the athlete sprints to the baseline to cone 2 and shuffles to the right to cone 3
  - The athlete then backpedals to cone 4 and shuffles left back to cone 1
  - The athlete immediately changes the direction of the drill by shuffling back to the right (cone 4), sprinting to the baseline (cone 3), shuffling left (cone 2), and then backpedaling to finish in the same spot as the starting point (cone 1)

Table 3.23 Comparative Lane Agility Drill Score Ranges for Players by Sex and Position [98]

Position	Males (time in seconds)	Females (time in seconds)
Guards	10.2 – 10.9	13.0 – 14.5
Forwards	11.0 – 11.4	14.6 – 15.5
Centers	11.5 – 12.3	14.6 – 15.5

REFERENCES:

1. Da Silva, C. D., Bloomfield, J., & Marins, J. C. B. (2008). A review of stature, body mass and maximal oxygen uptake profiles of U17, U20 and first division players in Brazilian soccer. *Journal of Sports Sciences and Medicine, 7*(3), 309.

2. Penry, J. T., Wilcox, A. R., & Yun, J. (2011). Validity and reliability analysis of cooper's 12-minute run and the multistage shuttle run in healthy adults. *Journal of Strength and Conditioning Research, 25*(3), 597.

3. Leger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6*(2), 93-101.

4. Ramsbottom, R., Brewer, J., & Williams, C. (1988). A progressive shuttle run test to estimate maximal oxygen uptake. *British Journal of Sports Medicine, 22*(4), 141-144.

5. Cooper, K. H. (1968). A means of assessing maximal oxygen intake: Correlation between field and treadmill testing. JAMA: *The Journal of the American Medical Association, 203*(3), 201-204.

6. Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Bangsbo, J. (2003). The yo-yo intermittent recovery test: Physiological response, reliability, and validity. *Medicine and Science in Sports and Exercise, 35*(4), 697-705.

7. Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The yo-yo intermittent recovery test: A useful tool for evaluation of physical performance in intermittent sports. *Sports Medicine, 38*(1), 37-51.

8. Lavoie, J. M., Leger, L. A., Leone, M., & Provencher, P. J. (1985). A maximal multistage swim test to determine the functional and maximal aerobic power of competitive swimmers. *Journal of Swimming Research, 1*, 17-22.

9. Carey, D. G., Drake, M. M., Pliego, G. J., & Raymond, R. L. (2007). Do hockey players need aerobic fitness? Relation between VO_2max and fatigue during high-intensity intermittent ice skating. *The Journal of Strength and Conditioning Research, 21*(3), 963-966.

10. Arseneau, E., Mekary, S., & Léger, L. A. (2011). VO_2 requirements of boxing exercises. *The Journal of Strength and Conditioning Research, 25*(2), 348.

11. Cronin, J., & Crewther, B. (2004). Training volume and strength and power development. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 7*(2), 144-155.

12. McGill, S. M., Grenier, S., Kavcic, N., & Cholewicki, J. (2003). Coordination of muscle activity to assure stability of the lumbar spine. *Journal of Electromyography and Kinesiology, 13*(4), 353-359.

13. Luoto, S., Heliövaara, M., Hurri, H., & Alaranta, H. (1995). Static back endurance and the risk of low-back pain. *Clinical Biomechanics, 10*(6), 323-324.

14. Koumantakis, G. A., Watson, P. J., & Oldham, J. A. (2005). Supplementation of general endurance exercise with stabilisation training versus general exercise only. Physiological and functional outcomes of a randomised controlled trial of patients with recurrent low back pain. *Clinical Biomechanics (Bristol, Avon), 20*(5), 474.

15. McGill, S. M., Childs, A., & Liebenson, C. (1999). Endurance times for low back stabilization exercises: Clinical targets for testing and training from a normal database. *Archives of Physical Medicine and Rehabilitation, 80*(8), 941-944.

16. Ito, T., Shirado, O., Suzuki, H., Takahashi, M., Kaneda, K., & Strax, T. E. (1996). Lumbar trunk muscle endurance testing: An inexpensive alternative to a machine for evaluation. *Archives of Physical Medicine and Rehabilitation, 77*(1), 75-79.

17. Evans, K., Refshauge, K. M., & Adams, R. (2007). Trunk muscle endurance tests: Reliability, and gender differences in athletes. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 10*(6), 447-455.

18. Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: The use of fundamental movements as an assessment of function–Part 1. *North American Journal of Sports Physical Therapy: NAJSPT, 1*(2), 62.

19. Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: The use of fundamental movements as an assessment of function–Part 2. *North American Journal of Sports Physical Therapy: NAJSPT, 1*(2), 62.

20. Kiesel, K., Plisky, P. J., & Voight, M. L. (2007). Can serious injury in professional football be predicted by a preseason functional movement screen? *North American Journal of Sports Physical Therapy: NAJSPT, 2*(3), 147.

21. Shultz, R., Anderson, S. C., Matheson, G. O., Marcello, B., & Besier, T. (2013). Test-retest and interrater reliability of the functional movement screen. *Journal of Athletic Training, 48(*3), 331.

22. Butler, R. J., Plisky, P. J., Southers, C., Scoma, C., & Kiesel, K. B. (2010). Biomechanical analysis of the different classifications of the functional movement screen deep squat test. *Sports Biomechanics / International Society of Biomechanics in Sports, 9*(4), 270-279.

23. Noda, T. & Verscheure, S. (2009). Individual goniometric measurements correlated with observations of the deep overhead squat. *Athletic Training and Sports Health Care, 1*(3), 114.

24. Wilson, G. J., Wood, G. A., & Elliott, B. C. (1991). The relationship between stiffness of the musculature and static flexibility: an alternative explanation for the occurrence of muscular injury. *International Journal of Sports Medicine, 12*(04), 403-407.

25. Renkawitz, T., Boluki, D., & Grifka, J. (2006). The association of low back pain, neuromuscular imbalance, and trunk extension strength in athletes. *The Spine Journal, 6*(6), 673-683.

26. Granata, K. P., & England, S. A. (2006). Stability of dynamic trunk movement. *Spine, 31*(10), E271.

27. Cohen, D. B., Mont, M. A., Campbell, K. R., Vogelstein, B. N., & Loewy, J. W. (1994). Upper extremity physical factors affecting tennis serve velocity. *The American Journal of Sports Medicine, 22*(6), 746-750.

28. Brown, L. P., Niehues, S. L., Harrah, A., Yavorsky, P., & Hirshman, H. P. (1988). Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *The American Journal of Sports Medicine, 16*(6), 577-585.

29. Ellenbecker, T. S., Roetert, E. P., Bailie, D. S., Davies, G. J., & Brown, S. W. (2002). Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Medicine and Science in Sports and Exercise, 34*(12), 2052-2056.

30. Beaudoin, C. M., & Whatley Blum, J. (2005). Flexibility and running economy in female collegiate track athletes. *The Journal of Sports Medicine and Physical Fitness, 45*(3), 295-300.

31. Jones, A. M. (2002). Running economy is negatively related to sit-and-reach test performance in international-standard distance runners. *International Journal of Sports Medicine,23*(1), 40-43.

32. Gleim, G. W., Stachenfeld, N. S., & Nicholas, J. A. (1990). The influence of flexibility on the economy of walking and jogging. *Journal of Orthopaedic Research, 8*(6), 814-823.

33. Craib, M. W., Mitchell, V. A., Fields, K. B., Cooper, T. R., Hopewell, R., & Morgan, D. W. (1996). The association between flexibility and running economy in sub-elite male distance runners. *Medicine and Science in Sports and Exercise, 28*(6), 737.

34. Godges, J. J., MacRae, H., Longdon, C., Tinberg, C., & Macrae, P. G. (1989). The effects of two stretching procedures on hip range of motion and gait economy. *The Journal of Orthopaedic and Sports Physical Therapy, 10*(9), 350.

35. Malina, R. M. (1995). Anthropometry. Physiological assessment of human fitness, 205-219.

36. Reiman, M. P., & Manske, R. C. (2009). Functional testing in human performance. Human Kinetics.

37. Olds, T. (2004). The rise and fall of anthropometry. *Journal of Sports Sciences, 22*(4), 319-320.

38. Schranz, N., Tomkinson, G., Olds, T., & Daniell, N. (2010). Three-dimensional anthropometric analysis: Differences between elite Australian rowers and the general population. *Journal of Sports Sciences, 28*(5), 459-469.

39. Wells, G. D., Elmi, M., & Thomas, S. (2009). Physiological correlates of golf performance. *The Journal of Strength and Conditioning Research, 23*(3), 741-750.

40. Wang, J., Thornton, J. C., Kolesnik, S., & Pierson, R. N. (2000). Anthropometry in body composition: an overview. *Annals of the New York Academy of Sciences, 904*(1), 317-326.

41. Pollock, M. L., & Jackson, A. S. (1984). Research progress in validation of clinical methods of assessing body composition. *Medicine and Science in Sports and Exercise, 16*(6), 606-15.

42. Gause-Nilsson, I., & Dey, D. K. (2004). Percent body fat estimation from skin fold thickness in the elderly. Development of a population-based prediction equation and comparison with published equations in 75-year-olds. *The Journal of Nutrition, Health and Aging, 9*(1), 19-24.

43. Brodie, D. A. (1988). Techniques of measurement of body composition Part I. *Sports Medicine, 5*(1), 11-40.

44. Jürimäe, T., Jagomägi, G., & Lepp, T. (1992). Body composition of university students by hydrostatic weighing and skinfold measurement. *The Journal of Sports Medicine and Physical Fitness, 32*(4), 387.

45. Garcia, A. L., Wagner, K., Hothorn, T., Koebnick, C., Zunft, H. J. F., & Trippo, U. (2005). Improved prediction of body fat by measuring skinfold thickness, circumferences, and bone breadths. *Obesity Research, 13*(3), 626-634.

46. Coleman, A. E., & Lasky, L. M. (1992). Assessing running speed and body composition in professional baseball players. *The Journal of Strength and Conditioning Research, 6*(4), 207-213.

47. NBA (2013) in NBA pre-Draft combine measurements and results. NBA.com. Retrieved January 28, 2014, from http://www.nba.com/2013/news/05/17/nba-draft-combine-results/

48. Bangsbo, J. (1994). Fitness training in football: a scientific approach. August Krogh Institute, University of Copenhagen.

49. Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences, 18*(9), 669-683.

50. Molinari L, Gasser T, Largo RH, Prader A. 1995. Child-adult correlations for anthropometric measurements. Hauspie R, Lindgren G, Falkner F, editors. Essays on auxology. Welwyn Garden City: Castlemead Publications. p 164–177.

51. Cole, T. J., & Wright, C. M. (2011). A chart to predict adult height from a child's current height. *Annals of Human Biology, 38*(6), 662.

52. Anderson, G., & Ward, R. (2002). Classifying children for sports participation based upon anthropometric measurement. *European Journal of Sport Science,2*(3), 1-13.

53. Margaria, R., Aghemo, P., & Rovelli, E. (1966). Measurement of muscular power (anaerobic) in man. *Journal of Applied Physiology, 21*(5), 1662.

54. Hetzler, R. K., Vogelpohl, R. E., Stickley, C. D., Kuramoto, A. N., DeLaura, M. R., & Kimura, I. F. (2010). Development of a modified margaria-kalamen anaerobic power test for american football athletes. *Journal of Strength and Conditioning Research, 24*(4), 978-984.

55. Clemons, J., & Harrison, M. (2008). Validity and reliability of a new stair sprinting test of explosive power. *The Journal of Strength and Conditioning Research, 22*(5), 1578-1583.

56. de Salles, P., Vasconcellos, F., de Salles, G., Fonseca, R., & Dantas, E. (2012). Validity and Reproducibility of the Sargent Jump Test in the Assessment of Explosive Strength in Soccer Players. *Journal of Human Kinetics, 33*(1), 115-121.

57. Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players – a review of observational and experimental studies. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 13*(3), 332-339.

58. Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players – a review of observational and experimental studies. *Journal of Science and Medicine in Sport / Sports Medicine Australia, 13*(3), 332-339.

59. Hoffman, J. (2006). Norms for fitness, performance, and health. Human Kinetics.

60. Castagna, C., & Castellini, E. (2013). Vertical jump performance in Italian male and female national team soccer players. *Journal of Strength and Conditioning Research, 27*(4), 1156-1161.

61. Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: A review of observational and experimental studies: Vertical jump in volleyball players. *Scandinavian Journal of Medicine and Science in Sports, 20*(4), 556-567.

62. Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine and Science in Sports and Exercise, 31*(4), 572-577.

63. Fox, E. L., & Mathews, D. K. (1974). *Interval Training: Conditioning for Sports and General Fitness* (pp. 257-258). Philadelphia: Saunders.

64. Harman, E. A., Rosenstein, M. T., Frykman, P. N., Rosenstein, R. M., & Kraemer, W. J. (1991). Estimation of human power output from vertical jump. *The Journal of Strength and Conditioning Research, 5*(3), 116-120.

65. Zupan, M. F., Arata, A. W., Dawson, L. H., Wile, A. L., Payn, T. L., & Hannon, M. E. (2009). Wingate anaerobic test peak power and anaerobic capacity classifications for men and women intercollegiate athletes. *The Journal of Strength and Conditioning Research, 23*(9), 2598-2604.

66. Baechle, T. R., & Earle, R. W. (Eds.). (2000). *Essentials of Strength Training and Conditioning.* Human kinetics.

67. Baechle, T. R., & Earle, R. W. (2000). Essentials of Strength and Conditioning (2nd). Human Kinetics: Champaign, IL.

68. Clemons, J. M., Campbell, B., & Jeansonne, C. (2010). Validity and reliability of a new test of upper body power. *The Journal of Strength and Conditioning Research, 24*(6), 1559-1565.

69. Marques, M. C., Gil, H., Ramos, R. J., Costa, A. M., & Marinho, D. A. (2011). Relationships between vertical jump strength metrics and 5 meters sprint time. *Journal of Human Kinetics, 29*(1), 115-122.

70. Little, T., & Williams, A. G. (2005). Specificity of acceleration, maximum speed, and agility in professional soccer players. *The Journal of Strength and Conditioning Research, 19*(1), 76-78.

71. Wilson, G. J., Newton, R. U., Murphy, A. J., & Humphries, B. J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine and Science in Sports and Exercise, 25*(11), 1279-1286.

72. Farrow, D., Young, W., & Bruce, L. (2005). The development of a test of reactive agility for netball: a new methodology. *Journal of Science and Medicine in Sport, 8*(1), 52-60.

73. Gabbett, T. J., Kelly, J. N., & Sheppard, J. M. (2008). Speed, change of direction speed, and reactive agility of rugby league players. *The Journal of Strength and Conditioning Research, 22*(1), 174-181.

74. Serpell, B. G., Ford, M., & Young, W. B. (2010). The development of a new test of agility for rugby league. *The Journal of Strength and Conditioning Research, 24*(12), 3270-3277.

75. Sporis, G., Jukic, I., Milanovic, L., & Vucetic, V. (2010). Reliability and factorial validity of agility tests for soccer players. *The Journal of Strength and Conditioning Research, 24*(3), 679-686.

76. NFL (2014) in NFL Top Performers – 60 yd Shuttle. NFL.com. Retrieved May 29, 2014, http://www.nfl.com/combine/top-performers#year=2014&workout=SIXTY_YARD_SHUTTLE&position=QB-RB-WR-TE-S-DL-LB-CB-OL-SPEC

77. Wheeler, K. W., & Sayers, M. G. L. (2011). Rugby union contact skills alter evasive agility performance during attacking ball carries. *International Journal of Sports Science and Coaching, 6*(3), 419-432.

78. Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Medicine, 41*(3), 221-232.

79. Davlin, C. D. (2004). Dynamic balance in high level athletes. *Perceptual and Motor Skills, 98*(3c), 1171-1176.

80. Matsuda, S., Demura, S., & Uchiyama, M. (2008). Centre of pressure sway characteristics during static one-legged stance of athletes from different sports. *Journal of Sports Sciences, 26*(7), 775-779.

81. Sell, T. C., Tsai, Y., Smoliga, J. M., Myers, J. B., & Lephart, S. M. (2007). Strength, flexibility, and balance characteristics of highly proficient golfers. *Journal of Strength and Conditioning Research, 21*(4), 1166-1171.

82. Bressel, E., Yonker, J. C., Kras, J., & Heath, E. M. (2007). Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *Journal of Athletic Training, 42*(1), 42.

83. Bell, D. R., Guskiewicz, K. M., Clark, M. A., & Padua, D. A. (2011). Systematic review of the balance error scoring system. *Sports Health: A Multidisciplinary Approach, 3*(3), 287-295.

84. Gribble, P. A., & Hertel, J. (2003). Considerations for normalizing measures of the star excursion balance test. *Measurement in Physical Education and Exercise Science, 7*(2), 89-100.

85. Hertel, J., Miller, S., & Denegar, C. (2000). Intratester and intertester reliability during the Star Excur sion Balance Test. *Journal of Sport Rehabilitation, 9*(2), 104–116.

86. Malliou, P., Amoutzas, K., Theodosiou, A., Gioftsidou, A., Mantis, K., Pylianidis, T., & Kioumourtzoglou, E. (2004). Proprioceptive training for learning downhill skiing. *Perceptual and Motor Skills, 99*(1), 149.

87. Carson, R. G. (2006). Changes in muscle coordination with training. *Journal of Applied Physiology, 101*(5), 1506-1513.

88. Gelfand I.M., Tsetlin M.L. (1966) On mathematical modeling of the mechanisms of the central nervous system. In: Gelfand IM, Gurfinkel V.S., Fomin S.V., Tsetlin M.L. (Eds.) *Models of the Structural-Functional Organization of Certain Biological Systems*, pp.9-26, Nauka: Moscow, Russia (in Russian, a translation is available in 1971 edition by MIT Press: Cambridge, MA).

89. Jacobs, R., Bobbert, M. F., & van Ingen Schenau, G. J. (1996). Mechanical output from individual muscles during explosive leg extensions: the role of biarticular muscles. *Journal of Biomechanics, 29*(4), 513-523.

90. Leirdal, S., Roeleveld, K., & Ettema, G. (2008). Coordination specificity in strength and power training. *International Journal of Sports Medicine, 29*(03), 225-231.

91. Egan, C. D., Verheul, M. H. G., & Savelsbergh, G. J. P. (2007). Effects of experience on the coordination of internally and externally timed soccer kicks. *Journal of Motor Behavior, 39*(5), 423-432.

92. Tessitore, A., Perroni, F., Cortis, C., Meeusen, R., Lupo, C., & Capranica, L. (2011). Coordination of soccer players during preseason training. *The Journal of Strength and Conditioning Research, 25*(11), 3059-3069.

93. Paul, M., Biswas, S. K., & Sandhu, J. S. (2011). Role of sports vision and eye hand coordination training in performance of table tennis players. *Brazilian Journal of Biomotricity, 5*(2).

94. Sallet, P., Perrier, D., Ferret, J. M., Vitelli, V., & Baverel, G. (2005). Physiological differences in professional basketball players as a function of playing position and level of play. *The Journal of Sports Medicine and Physical Fitness, 45*(3), 291-294.

95. Hoffman, J. R., Tenenbaum, G., Maresh, C. M., & Kraemer, W. J. (1996). Relationship between athletic performance tests and playing time in elite college basketball players. *The Journal of Strength and Conditioning Research, 10*(2), 67-71.

96. Przybylski, S., Makar, P., & Bielec, G. (2012). Test 8× 32.8 m as a Diagnostic and Fitness Level Control Indicator in Basketball (Diagnostic Test in Basketball). *Baltic Journal of Health and Physical Activity, 4*(1), 7-14.

97. Abdelkrim, N. B., El Fazaa, S., & El Ati, J. (2007). Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *British Journal of Sports Medicine, 41*(2), 69-75.

98. Sigmon, C. (2005). Agility Drills. FIBA Assist Magazine, 17, 62. FIBA.com. Retrieved May 29, 2014, http://www.fiba.com/asp_includes/download.asp?file_id=612