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Power! A Field Based Testing Resource for Strength & Conditioning Personnel

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ABSTRACT

Power may be the most vital physical trait towards successful sport performance. Whether competing in team sports such as basketball and rugby; individual sports including track and field events, tennis, and golf; endurance based events encompassing cross country skiing, marathon running, and long distance swimming; or even tactical occupations, power development and maintenance is crucial to an athletes' success. The specific power component most vital to success should be identified, monitored, and tested to ensure continued development and/or maintenance throughout a competition calendar. By conducting a needs analysis, the specific contributions of power to a given sport can be determined. Equally important as knowing how to develop power, is also knowing what economic field based tests are available to accurately assess athletic development. The purpose of this article is to provide strength and conditioning coaches (SCC) across numerous levels/populations and having various levels of funding, with a brief overview, categorization and coaching resource for the vast array of field testing methods available to assess and monitor whole, upper, and lower body power.

Keywords: Muscular Power, Field Testing, Anaerobic Power, Terminology

INTRODUCTION

The term 'power' is often used in a broad scope, with varying definitions, depending on the population its being used by (32, 73, 78). In the field of strength and conditioning (S&C), concentrations possibly referring to power in various ways includes strength and conditioning coaches (SCC), sport scientists/researchers, sport coaches, athletes, athletic trainers, dietician/nutritionist, and therapists (73). The concept of power must be conveyed to the athlete as a coaching cue in language that is understandable to the athlete, not the sport scientist. When the SCC attempts to introduce the mechanical definition of power (32, 78) in S&C to convey information or coaching cues to athletes, the concept may be more complex than is necessary. Prior knowledge of how power is defined, calculated, and interpreted in different professions is beneficial to simplify the explanation because even staff members within a sport organization (SCC, dietician/nutritionist, sport scientist, etc.) may speak about power in various contexts. The population's background knowledge, experiences, and perspective are information to be considered when delivering a message. For this article's intended audience (high school, collegiate and professional SCC), 'power' is defined according to the most recent *Essentials of Strength Training and Conditioning* (4th ed.) text, "the time rate of doing work" (40), that is quantified and presented in Watts (W). Power has been used to describe athletic movements that present the displacement of the body or external load with maximal physical effort in the shortest amount of time. Additionally, the equation to obtain power is equal to force in Newtons (N) multiplied by distance measured in meters (m) and divided by time in seconds (s) (61). Thus, power is a measurable kinetic variable that may be assessed with several different, valid and reliable field and lab based tests. To fully understand the information presented in this manuscript, the definition for the measurable kinetic variable work must also be part of the conversation. Work does not include a time component, as is observed for power, and it is the product of force (N) multiplied by distance (m) and is measured in joules (J) (40).

Power can be assessed using both field and laboratory based tests that are dependent on the sport, deficient physical qualities, and/or expectations of the coaching staff. Owing to the importance of power in improving and sustaining high performance across numerous sports and athletic populations (13, 30, 43, 58, 62, 69, 71, 83), the necessity to know how to test, assess, and program for power development is paramount to improve individual and team sport success. For example, in the absence of measuring absolute power (Watts) a SCC can determine an athletes' ability to execute a single movement/repetition with the highest effort possible to put a shotput, snatch a maximal load, or long jump distance. The athlete can further be tested with a linear position transducer such as the GymAware™ FLEX (Kinetic Performance Technology, Australia) that can provide absolute power (Watts) or relative power (W/kg) which provides a value of power production relative to an individual's body mass. Selecting the most appropriate test, whether lab or field based, requires careful consideration to obtain the most sport specific movement power output for effective planning and programming. The purpose of this article focuses on selecting the most appropriate field based power test as a coaching resource to assist the SCC at all levels as laboratory/clinical tests may not be feasible due to a lack of equipment and/or funding, staffing shortages, and logistics. Due to the typical cost associated with purchasing and maintaining laboratory equipment (27), an array of field tests for power will be presented that could be used as a guide for effective test selection, measurement, and evaluation that can be applicable/presented to the athletes the SCC is providing guidance. Lab based power tests and methods are briefly presented for comparative purposes only and not to debate the reliability/validity of any test. The information presented for the various field tests can serve as a guide for the SCC to create effective programming directed towards improving the expression of a power movement and output most suitable to specific athletic populations. Figure 1 is a hierarchical representation of how power is commonly tested in a field based setting.

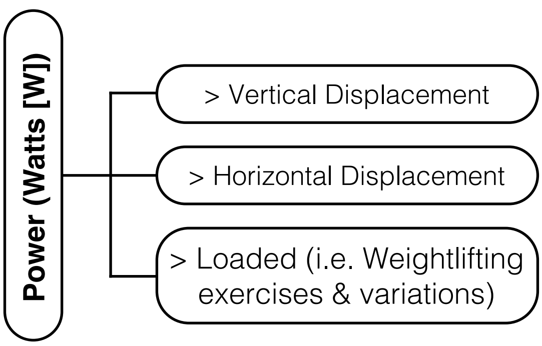

Figure 1. Field Based Power Testing Hierarchy

OVERVIEW OF POWER DEVELOPMENT

Power output is described as the body's ability to produce force at the highest muscular contraction velocity, which may be instantaneous or sustained for varying time durations, and are directly influenced by the force-velocity and length-tension relationships (13). Muscular power performance can be limited by muscle cross-sectional area, muscle-fiber composition and stretch-shortening cycle (SSC) activity, which may be modified by appropriate exercises/activity selection in a program. An increase in muscle cross-sectional area (i.e. muscular hypertrophy) lends itself to more contractile properties when compared with less muscle cross-sectional area, thus providing for greater power production (77). An athletes' muscle fiber type ratios (e.g., Type IIx:Type I) further individualizes power production. A greater proportion of type IIa and IIx muscle fibers over type I (slower contraction velocity; greater resistance to fatigue), represents a greater muscle cross-sectional area capable of producing high velocity muscular contractions, eventually leading to improved power output (36). Programs with effective, strategic exercise selection and order, using various types of jumps, plyometrics, ballistic movements, and resistance training exercises across the full force-velocity curve, can enhance SSC activity, contractile velocity and subsequently improve muscular power output (14, 36, 37).

Anaerobic power refers to an athletes' ability to complete short, high intensity bouts or actions (<30 seconds) and to perform high muscular power efforts near the end of an endurance event (48). Exercise categories of weightlifting movements (e.g., clean & jerk), short distance sprints (e.g. < 200m), and jumps, along with appropriate volume (sets x reps), intensity (e.g. % 1 repetition maximum [RM]), inter-set rest and exercise order can help with anaerobic and muscular power development and production (41). There are numerous sports that rely on anaerobic power (e.g., combat sports, Australian rules football, basketball, volleyball, and soccer) (20, 25, 27, 53, 56, 62). Training methods to improve anaerobic power production range from high-intensity interval training (HIIT), sprint interval training (SIT) to combined resistance training/ HIIT (18, 20, 44, 55). Readers are directed to the previously listed references on these training methods for a more detailed discussion on each. Ultimately, the information disseminated in this manuscript is directed towards the SCC that may not have additional coaches, equipment, software, or laboratory support to conduct sensitive power tests.

TESTING METHODS – FIELD VS. LAB - BASED

All tests should be valid and reliable when selecting the most appropriate test to assess physical abilities and obtain key performance indicators. A test first must establish reliability, which indicates how consistently and to what degree, the selected test is repeatable over time (42). Validity also needs to be established, ensuring the selected test measures exactly what it is intended to measure (42). A SCC can add a test of their own, in absence of peer-reviewed support, but once enough data is obtained for statistical analysis, they can also test for validity and reliability of their unique test. Nearly every SCC has their own unique coaching style and programming philosophies which may dictate completing validity and reliability tests of their unique power assessments that have yet to be published in peer-reviewed literature. In turn, the SCC can ensure their unique power tests have acceptable validity and reliability to test for precisely what they want to measure. Overall, a test may be reliable but lack validity. However, no test can be valid and not reliable. A more in-depth discussion on test validity and reliability may be found in Atkinson and Nevill (1), Hopkins (26), and Weakley et al. (75). Selecting the most appropriate test for the type of power being expressed during sport-specific demands/skills, along with the access to necessary equipment and feasibility, are critical considerations for the SCC. Coaches need the understanding that power testing can encompass multiple measurements, some of which may not be feasibly measured using field based tests. For the purpose of this manuscript, field based power tests for coaches to select will be presented as part of three distinct categories – whole, lower, and upper body – to be presented later in this manuscript. Ultimately, field and lab-based testing provides a broad generalization of the testing environment that a SCC can select to use an appropriate test(s).

The varying amounts of access to requisite testing equipment and technology delineates between practicality and research. Field based testing is most often utilized by SCC due to testing simplicity/swiftness and requiring less funding (27). Conversely, lab-based testing may often employ equipment not available to many SCC. The results of a sport's needs analysis will directly affect test selection (60), as the frequency and how power is most often expressed in a sport is relevant to assessing physical traits. The challenge with using lab-based tests, is that they may not be reflective of sport specific training, sport practices and/or competition environment. Lab-based tests may also provide an abundance of data that could delay a timely application towards programming adjustments and/or how relatable the data is to the coach and athlete. Furthermore, lab-based testing may provide kinetic and kinematic data that could distract from the intended measurement of focus for the sport coach (27). Thus, an experienced sport scientist, if and when possible, can investigate, comprehend, and effectively communicate if the data has use for programming effectiveness or is more appropriately used for monitoring (22). The authors of this manuscript are not suggesting to neglect using lab-based tests, but rather when possible, feasible, and appropriate, lab-based testing should be utilized as one piece of a holistic training program. However, for a large majority of SCC, field-based testing will provide a more ideal, practical, cost effective, and logistically possible approach for power testing (73). Table 1 categorizes and compares commonly used field and lab based testing methods and instrumentation for whole, lower, and upper-body power.

POWER TESTING

This section discusses field-based power tests with established validity and reliability that could be used to measure whole, lower, and upper body power. The basis for determining which test belongs in a particular category is determined by what body segment(s) are primarily responsible for completing a given test. For example, movements such as the snatch (SN), power clean (PCL), and backward overhead medicine ball throw (BOMBT) involve coordinated movement using the arms and legs as one system to complete a repetition, categorizing them as whole-body power tests. The squat jump

Table 1. Summary of Field and Lab-Based Test Methods and Instrumentation for Whole, Lower, and Upper Body Power

Category/Test	Field Testing Instrumentation	Laboratory Testing Instrumentation
Upper Body MB Throws/Puts; "Plyometric" Push-up	Tape Measure, Switch Mat; Biomechanical Analysis app. (e.g. Yogger: Movement Analysis™)	Timing System on Smith Machine Bench Throw; Stationary Grid Set Motion Analysis (3-D high speed cameras); Isokinetic Dynamometry – single joint measures (Biodex)
Lower Body Vertical or Horizontal Jumps & Hops	Vertec™; Switch Mat, Portable Force Plate (e.g. VALD™) & Accelerometer	Non-portable, In-Ground Force Plate e.g., AMTI™; Stationary Grid Set Motion Analysis (3-D high speed cameras); Isokinetic Dynamometry – single joint measures (Biodex)
Whole Body Snatch or Clean Pull; Power Clean	Barbell Kinetic & Kinematics (via Linear Position Transducer); Biomechanical Analysis app.	Non-portable, In-Ground Force Plate e.g., AMTI™; Stationary Grid Set Motion Analysis (3-D high speed cameras)

Medicine Ball – MB

(SJ) is performed with the person's hands on their belt line or holding a PVC pipe/wood stick across their upper trapezius, completed from a static start of flexed hips, knees, and ankle joints and followed by a rapid triple extension of each joint, classifying it as a lower body power test. Lastly, seated medicine ball chest throw (SMBT) that is completed with the arm and shoulder muscles is categorized as an upper body power test. The authors' intent is to reduce the *'paralysis by analysis'* phenomenon that a SCC could encounter when attempting to correctly select the most appropriate field-based test by using a simple and applicable categorization method.

Whole-Body Power Testing

Throws

Testing upper body power with 'throws' encompasses using backwards, sideways (forehand and backhand), overhead (OH), and rotational variations (33, 35, 64, 68, 70). The literature suggests that improving MB throw velocity and/or distance thrown shares a relationship with improved upper body power output (45). Thus, various MB throwing tests are an ideal choice for ease of implementation, practicality, validity and reliability for assessing upper body power. MB throwing tests only require a MB, tape measure, and when needed, an incline bench. Ultimately, various MB field-based tests can provide a viable option for SCC to assess whole body power (i.e. BOMBT) or upper body power.

In a study with 20 competitive sand volleyball players, Stockbrugger and Haennel (64) reported a strong correlation between a BOMBT test and a vertical countermovement jump (CMJ) test that was used to determine W via the Lewis formula (standardizes for body weight between subjects) (52). The BOMBT is performed by having an athlete stand with their heels aligned with the baseline, '0' point on a tape measure, with the MB held in front of the body and arms extended. In a countermovement action, the athlete descends to a quarter squat depth and rapidly coordinates movement between all involved joints to release the MB over their head at a 35-45° angle. The distance the MB is thrown is measured from baseline to where the MB impacts the ground. The greater the distance the MB is thrown in relation to body weight then relates to whole-body power. A further visualization of the BOMBT may be seen in Figures 2a and 2b. The BOMBT has been used in training and as a method of testing for predicting graduation from firefighter training academy, suggesting an additional application in tactical occupations (33, 34). Due to the countermovement and coordination of forces from the legs to the upper body in the BOMBT, the movement pattern observed in this test would justify it as a whole-body power measurement (64).

Regarding the overhead medicine ball (OHMB) throw, López-Plaza et al. (35) noted a meaningful, small effect size (ES) in their Top-10 ranked group (n = 40) for 200, 500 and 1,000m rowing events in young female sprint kayakers. Specifically, there was a significant association with the OHMB throw and 200m kayak sprint times ($r = -0.289$; $p < 0.05$). Ulbricht et al. (70) reported significant differences in relation to an OH, forehand and backhand (i.e. sideways) MB throw test between regional, and the more highly ranked, male national tennis

Figure 2a. BOMBT Start Position

Figure 2b. BOMBT End Position

players (n = 541). Specific statistical values for the OH, forehand and backhand MB throw tests, respectively, were reported as the following: male under 12 (r = -0.17, p = 0.07; r = -0.20, p = 0.03; r = -0.24, p = 0.01); male under 14 (r = -0.33, p = 0.00; r = - 0.42, p = 0.00; r = -0.40, p = 0.00); and male under 16 age groups (r = -0.37, p = 0.00; r = -0.43, p = 0.00; r = -0.45, p = 0.00). Female tennis players in the under 14 and under 16 age groups for the elite level also reported significant differences between regional and national ranked players (n = 274). Specific statistical values for the OH, forehand and backhand MB throw tests, respectively were reported as the following: female under 14 (r = -0.35, p = 0.00; r = -0.47, p = 0.00; r = -0.49, p = 0.00); and female under 16 age groups (r = -0.36, p = 0.00; r= -0.38, p = 0.00; r = -0.45, p = 0.00). Furthermore, Taniyama et al. (68) noted moderate correlations between rotational MB throws and bat swing velocity (r = 0.65; p = 0.003), pitching velocity (r = 0.62; p = 0.02), and batted baseball velocity (r = 0.53; p = 0.02) in a study with 35 National Collegiate Athletic Association (NCAA) Division III baseball players. The rotational MB throw is performed by an athlete standing with their feet about shoulder width apart and arms fully extended towards the ground holding the MB ~ 3 – 6m away from a wall. The athlete then rotates 90 degrees away from the wall before performing a rapid rotational countermovement using their legs and trunk musculature releasing the MB towards the wall. The MB velocity is measured by a standard radar gun ~ 1.2m off the ground and ~ 5m away from the athlete (68). Alternatively, velocity could be calculated by obtaining the distance of MB release to wall contact and the time to travel the distance through a phone motion analysis app. A greater velocity measurement from a rotational MB throw suggests greater power output and closely relates to increased pitch, swing, and batted ball velocity (68). The SCC would benefit from testing throwing power in all 3 planes of motion (frontal, sagittal and transverse) depending on the sport's requirements (i.e. basketball, baseball, tennis, lacrosse, etc.) with the relatively economical method of using a MB compared with laboratory testing. Athletes that demonstrate improvements in MB throw velocity and/or distance thrown allows for the assessment of program effectiveness towards improved whole body power. To be discussed later in this manuscript, the Smith machine bench press throw and rapid barbell bench press (both tests are simply common verbiage among SCC) are most appropriately placed as strict upper body power testing as the trunk and lower body are stabilized on a bench.

Weightlifting, Weight Training, and Externally Loaded "Plyometrics"

Sport specific muscular power may need to be assessed via an externally loaded exercise that can provide absolute, relative, maximal, mean, and peak power of the whole, upper, and/or lower body. An absolute power measurement includes the entire system (irrespective of bodyweight) whereas relative power is taken per unit of bodyweight (73) which is more critical in sports with weight classifications (i.e. combat sports, weightlifting, powerlifting). For example, a 1 RM power clean of 140kg by a 70kg athlete is an absolute measurement of the whole body's ability to display power. Conversely, the same weight power cleaned in relation to the athlete's bodyweight (i.e. 2x BW) is a relative whole body power measurement. Training programs seeking improvements in absolute power could implement weightlifting exercises (e.g. power snatch) at 60-80% 1 RM using less than 5 repetitions per set (11, 29, 67). Moreover, testing for maximal power will indicate the highest sustained power output measured for the duration of a test (73). Conversely, mean power output is the average of all recorded power measurements produced for each repetition in a given test (6). Thus, performing tests at submaximal loads can provide a valid, reliable, and reproducible muscular power measurement for static starts (concentric only) and countermovement actions. Given multiple expressions of power occur in sports similar to basketball, volleyball, soccer, American football, hockey, and rugby, the SCC should consider using similar testing methods to match the effort needs of the sport.

Peak power is the highest power output measured per sample of time (31) and can be measured as its own variable or in combination with other measurements (i.e. peak absolute power, peak relative power, etc.). As observed by Kawamori et al. (29) and Suchomel et al. (67) peak absolute power of the hang above knee power clean was attained between 60% to 80% 1 RM., while Pennington et al. (53), determined peak relative power output for the power clean was realized at intensities ≥ 80% 1RM. Cormie et al. (12) suggested programming vertical squat jumps and back squats may improve peak power using loads of 0% to 50% of a back squat 1 RM. An investigation by Pérez-Castilla et al. (54) examined using submaximal loading (≤ 85% 1RM) in a 3-repetition format, with both pause and rebound techniques in the back squat to determine peak and mean power. The results demonstrated that multiple effort testing in both pause and rebound techniques was an acceptable measurement of mean power, while peak power had greater variability (54). The multiple efforts of the preceding tests increased 'fatigue' and sharply decreased power output after several repetitions, making them ineffective at obtaining an accurate peak power output. Peak power is more appropriately assessed for by using single effort movements (e.g. discus) while maximal and mean power is more appropriate in sports requiring multiple, sustained, maximum effort movements (e.g. rugby). The SCC should consider that maximal, mean, and peak power have separate indicators of time, creating the necessity to know the distinction of when and what to test, for each. Determining which test would be most appropriate is established during the needs analysis and is further supported with subsequent test selection and administration, and programming. Furthermore, device sampling rates (i.e. 1,000 Hz) should also be considered if using these products for research and/or performing validity studies on a coaches unique power test when using software and instrumentation with this setting able to be calibrated.

Testing muscular power by using <5RM percentages for clean and SN variations (hang above knee, hang mid-thigh, power, etc.) have been established as being a valid and reliable testing application (17, 50) as both the clean and SN rely on rapid acceleration and force production to perform the exercise. Prior to using a clean or SN, the SCC should take the time (e.g., 2-4 weeks) for the athlete to safely demonstrate the ability to execute the lifts avoiding "at-risk" errors (e.g., reverse curl action of the bar, "starfish" catch position, etc.). Subsequently, if an athlete can proficiently execute the lift, displaying an increase in external load has suggested improvements in absolute and relative power while allowing for the transference of the movement to sport (76). As a result, SCC using the clean or SN to assess 1 RM changes may be the more economic and practical approach to determine improvements in muscular power when compared with lab based testing methods. Testing limitations may apply for power measurements at given percentages when using strength based tests. Although muscular strength tests, the back squat and supine bench press could be used to estimate power via linear position transducers (i.e. TENDO MyUnit, TENDO© Sport Machines, London, UK; GymAware™ FLEX, Kinetic Performance Technology, Australia) if loads are under 60% of their 1 RM (50, 61). These devices can vary in cost and may limit the expedience of testing a large group (n >15), which should be a consideration for the SCC. Very low, submaximal loads (< 30% 1 RM) could lead to technical changes occurring in an exercise and cause inaccurate peak power measurements if a measuring device is not used. Also, some devices may be limited based on a combination of the type of movement (ballistic or not) and load, so time should be taken to examine the validity and reliability of the device (3, 21, 49). Linear position transducers can provide several measurements of peak, absolute, and relative power during training that maximize individual athlete power output, which can complement the testing of these variables.

Lower-Body Power Testing

Jumps and Hops

The *'gold standard'* of lower body power testing is often considered to be done by using in-ground force plates to measure ground reaction forces and flight time or by video analysis to calculate the displacement of center of mass (79). Unfortunately, instruments such as in-ground force plates may be beyond a budget's capabilities, limited to a testing area, and not pragmatic for field based testing purposes. There are other instruments that are portable and more cost effective for field based testing to measure lower body power such as switch mats, jump height measurement devices (i.e. Vertec™), accelerometers, portable force plates, and linear position transducers. Lower body power tests may include measuring vertical and horizontal displacement using jump and hop variations from one of five categories - countermovement, squat, static squat, approach/attack, or repeat - that have demonstrated validity and reliability (7, 23, 24, 38, 39, 56, 65).

Jump tests provide lower body power assessments, that also maintain sport/movement specificity, with the added benefit of transferability to sprint and change of direction ability associated with sports played on a field or court (66). There are two test versions of the CMJ with the athlete either holding a stick across their back or hands held at, or below, their "belt line" through the entirety of the jump. The second variation of the CMJ involves coordinating the upper and lower limbs for the entirety of the jump with the arms swinging backwards then rapidly upward, as would be observed when testing using a Vertec™. Upper extremity involvement in the CMJ may increase jump height by up to 10% (79). The current manuscript will focus on the "hands at or below belt line"/ "hands on hips" variation of the CMJ as an assessment of lower body power. The "hands on hips" CMJ begins with a rapid descent, backwards shift of the hips, flexion of the knee joint, to a self-selected or practitioner selected depth before rapidly changing direction into a vertical jump (7). On the other hand, the SJ is carried out by having the athlete begin the test in a ½ squat static position, absent of a countermovement action prior to jumping (7). Markovic et al. (39) observed that the CMJ had the strongest relationship to the "explosive power factor"(r = 0.87) obtained from contact mats and digital timers in male, college-aged, physical education students (n = 93). The study demonstrated excellent validity and reliability using the CMJ (Intraclass correlation coefficient [ICC] = 0.98) and SJ (ICC = 0.97) as tests to assess lower body power when using contact mats and digital timers. This finding aids the SCC to assess athletes' lower body power due to a large majority of sports utilizing the SSC, likely demonstrating the appropriateness of using the CMJ test (i.e. similar movement patterns used for competitive performance).

Conversely, SJ are performed from the same starting position as a CMJ (relative joint angles of knees and hips) which can be self-selected by the athlete or SCC, but the athlete holds that position for an approximate duration of 2-4 seconds before proceeding into a vertical jump (7, 8, 80). The SJ is applicable to sports that require power development from a static start (e.g., track start, weightlifter, American football linemen). A strong relationship between the SJ and relative peak power of the SN and clean and jerk was observed by Carlock et al. (8) in USA national level weightlifters (n = 64). The SJ may need to be complemented with approach/attack jumps as a more sport specific testing method in sports such as volleyball and basketball that have a horizontal run up or step-in prior to a vertical jump being performed (56). Since sports with similar movements as volleyball and basketball are reliant on the summation of short sprints, change of direction ability, and vertical jumping, the approach variation would be the most appropriate to measure athletic performance capabilities (4, 5, 9, 63). A study by Pleša et al. (56) further supports this position, as moderate relationships between approach CMJ force-velocity variables were seen with sprinting (5 - 25m) (r = 0.53; p < 0.001) and change of direction ability (r = -0.58; p < 0.001) in volleyball players. These results from Pleša et al. (56) suggest a larger training focus should be placed on horizontal displacement in sports reliant on approach jump ability, in addition to short sprint and change of direction capabilities. In further support of using an approach CMJ as a test, Banda et al. (4) observed relationships to ¾ court sprint times, 10m sprint times, and the pro-agility test in NCAA D1 collegiate female basketball players. In sports requiring the ability to perform fast, short sprints, change of direction speed, and vertical jumping, using an approach/attack jump test may most closely resemble the physical qualities needed for successful performance while maintaining sport specific movement mechanics. Approach/attack jump testing may be most beneficial during the in-season training period when no new alterations to individual movement mechanics should be made (59).

Repeat jump tests are variations that would be beneficial for sports requiring the consecutive execution of a movement that is dependent on SSC activity. Possible repeated jump tests include the 10/5, Bosco repeated jump test (RJT), 20 repetition CMJ at 30% 1 RM of half squat (20CMJ), and 2 ½ minute loaded jump tests (2, 28, 51). The 10/5 repeated jump test requires athletes to perform 10 maximal effort vertical jumps on a switch mat (or video analysis app) analyzing the top 5 highest jumps with the shortest ground contact time (e.g., <250 ms) (24). Baker et al. (2) demonstrated validity and reliability in the 10/5 repeated jump test in adolescent athletes (ages 11 – 19) when examining ground contact time, flight time, and jump height. Overall, Baker et al. (2) observed the 10/5 repeated jump test to be a valid and reliable measure when implemented with athletes across a large age continuum, thus making this a potential field test, pending the availability of appropriate equipment.

An effective field test for lower body anaerobic power is the Bosco RJT that involves an athlete completing 30-seconds of repeated jumping with maximal effort, which can be measured with a switch mat, video analysis app, or linear position transducer. The Bosco RJT has demonstrated a lower fatigue index measure when compared with the Wingate Anaerobic Test (WAnT) suggesting a rationale for using the Bosco RJT to manage fatigue while measuring for anaerobic power (28). The Bosco RJT may be altered to match sport-specific demands, such as a 2 ½ minute loaded RJT for alpine downhill skiers (51). Alternatively, the 20CMJ is a variation of the Bosco RJT with the subject completing 20 repetitions of a CMJ using 30% of their half squat 1 RM in ~30 seconds. The 20CMJ was demonstrated to show good reliability when compared to the Bosco RJT (ICC > 0.90) (46). However, there were insignificant findings related to power decline when comparing a loaded repeat power assessment (i.e. 20CMJ) with the Bosco RJT, suggesting these tests may assess different qualities. In a separate investigation, Natera et al. (47) observed the 20CMJ to be a strong predictor of change of direction ability (r = 0.736; $p < 0.05$). Important notes for the SCC, are loaded RJTs (e.g., ~ 40% of athlete bodyweight, 30% of half squat 1 RM, etc.) should only be used with experienced athletes (e.g. >6 months of consistent S&C) and to use caution when implementing this test in populations with low training age (< 18 years old). Regardless, repeated jump ability has been associated with change of direction and acceleration speed (46, 81) making it appropriate for assessing athletic ability in team sports including basketball, rugby, and soccer.

Although 'horizontal power' is not a true kinetic variable (scalar or vector), it is a commonly used coaching term that needs to be addressed via the most effective testing and assessment method. For example, Mann et al. (38) demonstrated that standing long jump distance had a strong correlation to predicting individual peak power production in NCAA American football players. This study suggests horizontal displacement testing (e.g., standing long jump, triple hop test) could be used to assess bilateral and unilateral lower body power. The triple hop test was demonstrated as a valid predictor of clinical measures of lower body strength and power, including vertical jump height in collegiate soccer players (r^2 = 0.834; $p < 0.01$) (23). The observed relationship between triple hop distance and vertical jump height suggests this test could be potentially used for testing athletes' overall ability to express physical power. Furthermore, the triple hop test could possibly serve as an indicator of lower body imbalances and progression during a rehabilitation/return to play program. Given the implications of horizontal power tests to running, vertical jump height, and change of direction ability, these types of tests may be applicable to sports including tennis, American football, basketball, sprinting, and soccer.

Upper-Body Power Testing

Power tests are not exclusive to the lower body, as upper body power tests can be easily completed with MB, Smith machines, and barbells (10, 57, 61). As discussed earlier, a MB may be used to measure whole body power with the BOMBT, but there may be a need to strictly assess upper body power using throws or puts. Throws imply a rotational pattern of the object from start to release while a put has a linear "push" pattern and is typically performed with one arm only. Throw and put tests can be completed standing, wall supported, inclined, unilateral, and seated. Throw tests may also be completed while sitting absent back support to minimize the contribution of the lower body in the completion of the tests. Each of the preceding tests have been demonstrated to be practical, valid, and reliable methods to assess upper body power (10, 15, 57, 64). The United States Army physical testing battery was developed with 838 soldiers (19). Test battery 2, which included the MB put test, displayed a strong correlation (adjusted r^2 = 0.79 – 0.80; p < 0.01) in predicting performance on the Combat Arms military occupational specialties test and required no complex testing equipment (19). Further suggestion of MB throws or puts to assess upper body power was demonstrated by Clemons et al. (10) when comparing a novel bench press power test (timed barbell movement) to the seated 45° incline MB put test. Furthermore, sport and occupational performance may require unilateral power for successful performance. To assess for upper body unilateral power, a unilateral MB put test may be implemented, as Sánchez-Pay et al. (57) observed excellent inter-trial reliability and predictive validity (ICC = 0.97) between the standing MB put and tennis serve velocity (r = 0.932; r^2 = 0.869; p < 0.01). To assess for upper body bilateral symmetry, using a seated unilateral shotput has demonstrated good validity and reliability when used with the limb symmetry index (ICC = 0.82) (16).

While a MB put or shot test are appropriate for field testing of upper body power, an alternative weight room test for evaluating upper body power, as investigated by Shim et al. (61), is in the form of a rapid bench press pushing action using a Smith machine. The study used a digital timing device, in addition to measurements of force and distance to determine upper body power. Using updated technology via current motion analysis phone apps, time and distance can be obtained without a set system. Shim et al. (61) suggested peak power is measured at approximately 50% 1 RM, with measurement uniformity observed using loads of 25 – 75% 1 RM. The preceding intensities were supported via strong correlations (r = 0.987) between the Smith machine bench press push field test and an upper body isokinetic dynamometer. A similar upper body movement was investigated by Clemons et al. (10) utilizing a traditional free barbell supine bench press (SBP) using set loads for males and females (~61kg and ~25kg, respectively). The SBP was performed by subjects pushing the barbell off their chest as fast as possible until the bar broke through the laser beam timing device set at 0.3m above chest height. The time of the SBP was compared to a 45° incline seated MB bilateral put and demonstrated moderate to strong correlations as tests of upper body power for both males (r = 0.86; p < 0.00) and females (r = 0.79; p < 0.00). A limitation of the Smith machine bench press is the minimal number of Smith machines available along with being limited to a manageable number of participants to test (e.g., n < 15). Another possible upper body power test is via using the countermovement power push-up (CMPP) that is performed on a switch mat and would measure the displacement of a person's upper body (72). The CMPP has also been referred to as a 'plyometric push-up' or 'ballistic push-up' and has demonstrated increased performance as it relates to upper body kinematic and kinetic variables related to already established tests (74, 82). The CMPP can be efficiently applied to a large number of athletes (e.g., n = 24) and modified based on ability (e.g., from knees) making this test ideal for team sport settings and with athletes of various ability

Table 2. Whole, Lower, and Upper Body Field Based Power Tests

Throws	Puts/Push	Jumps	Hops	External Resistance – 1 RM
BOMBT	Standing Put	SJ/SSJ	Squat Hop	Loaded CMJ
OH Throw	Back Supported Put/45° Put	CMJ	CM Hop	Loaded SJ
Sideways (Forehand & Backhand)	CMPP	Approach/Attack Jump	Approach Hop/Leap	Clean & variations
Side Rotational Throw	Unilateral (Standing & Seated)	10/5 Repeated Jump Test	Triple-Hop	Snatch& variations
Barbell Bench Press Throw	Seated & Seated Absent Back Support	Bosco 30-second RJT	Triple Bounds (Triple jump approach)	2 ½ Minute Loaded Jump Test (Barbell)/ Loaded 20 CMJ
MB Hammer Throw	Smith Machine Bench Press (Push)	Standing Long Jump	Standing Long Hop	Hex Bar SJ

(Medicine Ball – MB; Overhead – OH; Backwards Overhead Medicine Ball Throw – BOMBT; Countermovement Power Push up – CMPP; Countermovement Jump – CMJ; Squat Jump – SJ; Static Squat Jump – SSJ; 20 repetition loaded (@30% half squat 1 RM) CMJ – 20CMJ; Bosco 30-second Repeated Jump Test – RJT; Countermovement - CMJ)

levels. The SCC ultimately needs to consider what upper body power test would be the most efficient and appropriate to implement, most specific to the individual sport, provides the most beneficial information for planning/programming, and can be easily repeated. Table 2 provides a summary of the various whole, lower, and upper body field based power tests, and examples of test variations, discussed throughout this manuscript. Figures 3a through 6c provides further visual demonstration of several of the unique field tests presented to measure for muscular power.

PRACTICAL APPLICATIONS

Literary consensus exemplifies the importance of muscular power development and maintenance towards individual and team sport success (13, 30, 43, 58, 62, 69, 71, 83). Included throughout this review are more than 2 dozen field based power tests to serve as an economical coaching resource for SCC at all levels to test for muscular power based on their unique setting, funding, population, and available testing equipment. Table 2 provided a brief summary/coaching resource for SCC to quickly refer to when selecting field based tests to measure power development most appropriate for their sport. Figures 2a-6c provides visual representation of several unique, selected tests from Table 2. SCC should determine if the test being implemented is for monitoring weekly fatigue or is being used to assess program effectiveness for sport-specific power development. The information presented on various field based tests and power development should further develop an understanding of the testing needs to create programming for a wide variety of athletes. The overview of field based power testing presented may assist SCC to determine and implement the most appropriate test(s) for different measures of power, based on a given sport. By using the various field based testing methods discussed, the information collected from testing can be used to enhance program effectiveness toward sport-specific power development.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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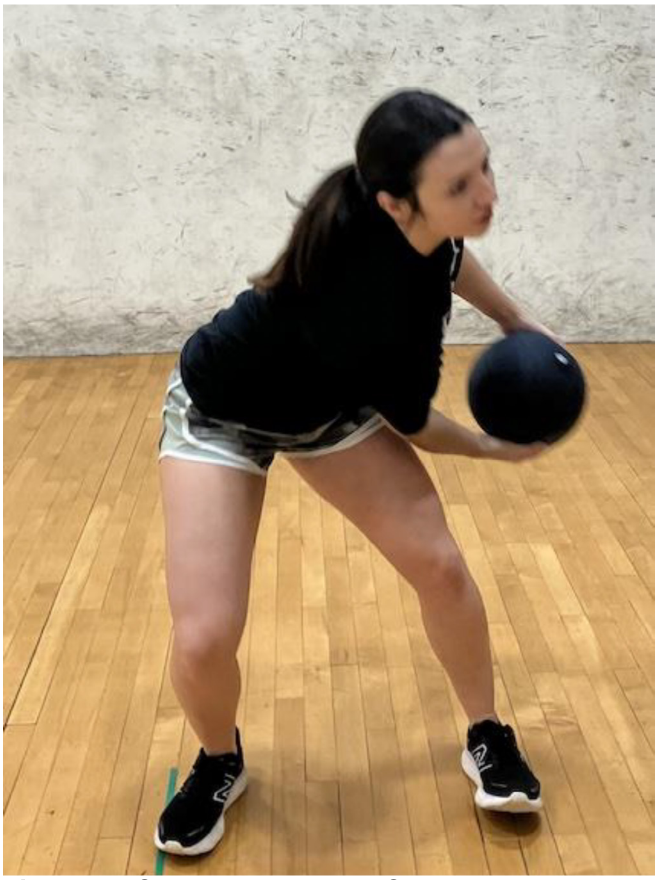

Figure 3a. Sideways MB Throw Start Position

Figure 3b. Sideways MB Throw End Position

Figure 4a. Standing OH MB Throw Start Position

Figure 4b. Standing OH MB Throw End Position

Figure 5a. Inclined (45-degree) MB Throw Start Position

Figure 5b. Inclined (45-degree) MB Throw End Position


Figure 6a. Triple Hop Test – Hop 1

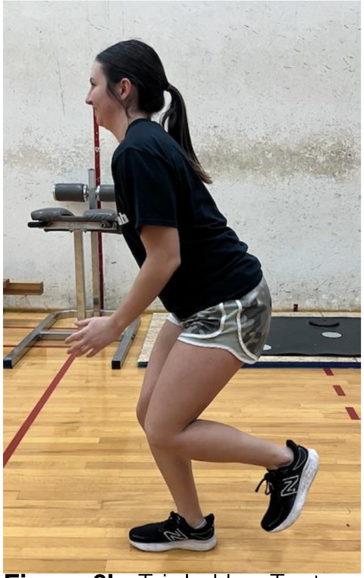
Figure 6b. Triple Hop Test – Hop 2


Figure 6c. Triple Hop Test – Hop 3

ETHICAL APPROVAL

Ethics for this study were approved in line with University's ethics procedure.

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