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ASEP Procedures Recommendation

ASEP PROCEDURES RECOMMENDATION I: ACCURATE ASSESSMENT OF MUSCULAR STRENGTH AND POWER

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ABSTRACT

LEE E. BROWN AND JOSEPH P. WEIR. **ASEP Procedures Recommendation I: Accurate Assessment Of Muscular Strength And Power. JEPonline.** 2001;4(3):1-21. The content of this manuscript is intended to assist the reader in collecting valid and reliable data for quantifying muscular strength and power. Various drawbacks and pitfalls of specific tests, as well as recommendations for the practitioner are also provided. The content is divided into sections covering isometric, isotonic, field tests, and isokinetic modes of exercise. Inherent in these modes are both concentric and eccentric muscle actions as well as both open and closed kinetic chain activities. For Isometric testing, contractions should occur over a four to five seconds duration with a one second transition period at the start of the contraction. At least one minute of rest should be provided between contractions. For each muscle tested at each position, at least three contractions should be performed although more may be performed if deemed necessary by the tester. For isotonic testing, the 1-RM test should be performed. After the general warm-up, the subject should perform a specific warm-up set of 8 repetitions at approximately 50% of the estimated 1-RM followed by another set of 3 repetitions at 70% of the estimated 1-RM. Subsequent lifts are single repetitions of progressively heavier weights until failure. Repeat until the 1-RM is determined to the desired level of precision. The rest interval between sets should be not less than one and not more than five minutes. The optimal number of single repetitions ranges from three to five. Data and guidelines of the following field tests are also provided; vertical jump, bench press, Wingate anaerobic cycle test (WAT), and the Margaria stair-run test. For isokinetic testing, details are provided for testing peak torque, work, power, endurance, and estimation of fiber type percentages.

Key Tems: Resistance, Exercise, Isokinetic, Isotonic, Isometric, Contraction

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INTRODUCTION

The assessment of strength and power is fundamental to athletic and human performance. Accurate knowledge of an individual's present level of muscular strength is important for both occupational functional capacity evaluation and appropriate athletic and rehabilitation exercise prescription. This paper is designed to assist the reader in collecting valid and reliable data pertaining to muscle strength and power. It is also designed to point out various drawbacks and pitfalls as well as recommendations for the practitioner. To this end, this paper lays the framework for the proper techniques of collection and interpretation of strength and power tests. It is divided into sections covering isometric, isotonic and isokinetic modes of exercise. Inherent in these modes are both concentric and eccentric muscle actions as well as both open and closed kinetic chain activities. While it is beyond the scope of this paper to detail specific aspects of each of these, the reader should be aware that the guidelines stated herein apply across each variation of human strength and power expression discussed.

GENERAL CONSIDERATIONS

Certain aspects of strength and power testing are generic to isometric, isotonic, and isokinetic measures. These include planning, safety, warm-up, familiarization, and specificity. These issues will be addressed here and factors that are unique to the specific testing modes will be addressed in the appropriate sections below.

Planning

Before undertaking any strength or power test a thorough plan should be in place regarding the type of data to be acquired. For example, in isokinetic testing one may choose to record peak torque, peak or average power**,** or work performed by the specific muscle group of interest. An examiner must determine *a priori* why and what they are testing prior to the evaluation and what specific information is of interest. As noted below, strength and power testing is specialized and returns information based on precise anatomical configurations, muscle length-tension relationships and velocities of muscle action. The practitioner must also be aware of data reduction techniques designed to eliminate extraneous information. If a clear understanding of the limitations of testing is established prior to interpretation, there will be little chance for erroneous conclusions.

Safety

Suitable safety measures should be in place prior to commencing any testing battery. These include, but are not limited to, inspection of equipment for broken or frayed components, appropriate lighting and temperature of the environment as well as removal of all hazards near and around the testing site. Emergency procedures need to be formalized. All testing personnel need to be familiar with these procedures and be certified in basic life support**.** Most importantly**,** all testing should be conducted under the diligent supervision of individuals experienced in physiological testing and measurement (i.e. an exercise physiologist with ASEP certification - EPC). Attention to these simple safety measures will help ensure the protection of both examiner and examinee.

Warm Up

While there is little data directly supporting decreased injury risk associated with warm up activities, it is physiologically reasonable to presume that increased muscle temperature and associated increased muscle elasticity decreases injuries associated with testing. Warm up activities should include both a general and specific warm up. The general warm up should consist of light activities such as low resistance leg or arm cycling designed to raise muscle temperature. Specific warm up activities should include static stretching of the muscle that will undergo testing. Additional warm up activities involving performing the actual test motions are addressed in the specific test mode sections below.

Familiarization

Many of the individuals who will undergo strength and power testing may have little or no experience performing the strength testing maneuvers. While strength testing has generally been shown to be reliable (2), novice subjects will likely improve strength scores on subsequent testing simply due to increased familiarity and comfort with the testing (54,71). This is especially true for strength tests that require relatively higher levels of motor skill such as isotonic testing with free weights. If possible, novice subjects should be given a familiarization session prior to actual testing. This should involve having the subject proceed through the entire test protocol while giving maximal effort. The subsequent testing session should occur at a time in which residual muscle soreness is over (e.g., 2 to 3 days).

Specificity

It is well established that various aspects of strength are associated with high levels of specificity. For example, many testing devices on the market today are designed to test and exercise muscles using the open kinetic chain. That is, only the isolated muscles of one joint are being examined. The information gathered from this type of testing will lead the examiner to specific conclusions regarding that single joint. Different results and conclusions may occur with multi-joint testing. Similarly, strength data derived from one type of contraction mode may correlate poorly with data from another mode. Throughout, it should be kept in mind that testing should be as specific as possible to the setting in which the information will be applied.

ISOMETRIC TESTING

Isometric contractions are muscle contractions in which the length of the muscle remains constant. No movement occurs and therefore no physical work is performed; however in a strict sense, isometric contractions do result in small changes in muscle fiber length and stretching of the elastic components of the muscle. Isometric testing is also called static testing. The primary advantage of isometric strength testing is that, with the proper equipment, it is relatively quick and easy to perform which lends itself to testing of large groups of subjects. A variety of devices have been used to measure isometric strength. These include cable tensiometers, strain gauges, and isokinetic dynamometers (with speed set to zero). In addition, with the exception of isokinetic devices, testing equipment is relatively inexpensive. Further, computer interfacing with isometric recording devices allows for the calculation of additional variables besides strength, such as the rate of force development (35). Testing at multiple joint angles allows for determination of strength throughout the range of motion.

The primary disadvantage of isometric testing is that the strength values recorded are specific to the point(s) in the range of motion at which the isometric contraction occurred, and strength scores at one position may be poorly correlated with strength scores at other positions (65,90). In addition, since most physical activities are dynamic, it has been questioned whether static strength measures provide strength data that are specific to activities of interest, and there are conflicting results in the literature as to whether isometric testing is predictive of dynamic performance (88). However, isometric strength testing has been shown to provide information predictive of occupational injuries associated with dynamic lifting tasks (22,45). Further, conflicting results regarding static versus dynamic relationships may be a reflection of the joint angle used during isometric testing (65).

In general, isometric strength testing has been shown to be highly reliable as assessed by reliability coefficients (correlations between 0.85 and 0.99) (2). However, there may still be systematic error. For example, Kroll (54) found high reliability (0.93) for repeated testing of the wrist flexors when analyzed with intraclass correlation coefficients (ICC). However, significant differences in mean values were found across test days. Similarly, Reinking et al. (71) found a relatively high reliability coefficient (ICC = 0.80, standard error of the mean (SEM) = 19.4% of mean) for isometric testing of the quadriceps (60° of knee flexion) on separate days. However, the mean values were significantly different, indicating that there were systematic increases in isometric force across test days. These results suggest that a separate practice session prior to actual testing may facilitate maximal performance and avoid introduction of systematic bias due to learning effects.

A variety of factors need to be considered with isometric testing. These include the joint angle at which to perform the testing, the rest interval between consecutive repetitions, the number of repetitions to perform, the duration of the contraction, and the time interval over which the force or torque is calculated. To date, there are no specific guidelines for these factors and little data exists which evaluates different procedures.

Joint Angle

If isometric data are needed for defining strength at specific positions, then testing at joint angles associated with these positions is warranted (22). However, if there is no joint angle preference, then other criteria for joint angle selection may be used. Sale (73) has suggested that testing at the joint angle associated with the maximum force output may serve to decrease error associated with minor errors in joint positioning. For example, the knee position associated with maximal knee extensor force is approximately midway between full extension and full flexion at approximately 65 degrees (55). Force-angle curves have been reported for a variety of joints (55) which can be used to choose the joint angle to be tested.

Duration of Contractions

Sale (73) suggests that isometric contractions of five seconds duration are long enough to allow for peak force development. Further, subjects can only maintain force at maximum for ≤ 1 second (73). Caldwell et al. (20) recommended a contraction duration of four seconds with a one second transition period from rest to maximal force. They also suggested that a four-second exertion ensures that a three-second plateau will occur and that the mean force over this three-second period be recorded. Similarly, Chaffin (21) recommended contraction durations of four to six seconds. Collectively, the available literature indicates that a contraction period with a one-second-transition period and a four to five second plateau should be sufficient to achieve a maximal isometric contraction. It should be noted however, that these recommendations are derived from experience of the cited authors as opposed to experimental validation.

Rest Intervals

A variety of rest intervals have been proposed in the literature. Sale (73) has suggested that one minute of rest be provided between trials. Caldwell et al. (20) recommended a rest interval of two minutes. Chaffin (21) recommended two minutes of rest between trials if a large number of trials (e.g., 15) are performed but rest intervals may be as short as 30 seconds if only a few trials are performed. Collectively, the available literature suggests that a one-minute rest period should be sufficient to allow adequate recovery between trials. It should be noted however, that these recommendations are derived from testing experience as opposed to experimental validation.

Number of Repetitions

Edwards et al. (29) used three maximal voluntary contractions in testing the quadriceps since the first contraction was usually “tentative”, while the second and third maximal contractions were usually similar to one another (coefficient of variation = 2.8%). Zeh et al. (90) reported that the mean of three trials was highly correlated with the first score of the three and concluded that one repetition provides “a reasonably good indicator of the subject’s strength in that position”. They also noted that use of two repetitions increased the precision of the measurement. The advantages of using few test repetitions is decreased injury risk, especially for testing that stresses the lumbar spine (90). In addition, fewer repetitions will minimize the confounding effects of fatigue on the strength data. However, their regression analysis did not address potential systematic bias in the use of only one or two trials. While there is no consensus in the literature, three test repetitions are likely to be sufficient to elicit a maximal value.

Averaging Interval

Simple mechanical recording devices (e.g., cable tensiometers) typically record the peak force or torque during a contraction. However, computer interfacing of the recording devices allows for the recording of the mean force or torque over a given time period. Chaffin (21) has recommended that forces/torques be averaged over a three second time interval which “avoids the errors induced by tremor and motion dynamics”, however there is no data directly supporting the superiority of a three second averaging interval over other time intervals. Further, Sale (73) notes that subjects can only maintain force for ≤ 1 second, which suggests that the three-second recommendation of Chaffin (21) may be too long.

Standardization of Instructions

Caldwell et al. (20) reported high variability in the force-time curves of subjects tested with different instructions from the tester. They argued that subjects require “explicit instructions” or else they will “develop their own strategies reflecting diverse interpretation of the task”. Chaffin (21) further recommends that instructions should be non-emotional and objective and that factors such as noise, spectators, etc be avoided.

Positioning and Stabilization

Because muscle force is affected by muscle length, and torque output is affected by muscle force and moment arm (53), changes in positioning can result in changes in isometric measurements that are independent of actual differences in muscle strength. This is true not only for the specific joint tested but also in adjacent joints that are crossed by a common muscle. For example, the hamstrings cross both the hip and knee joints and changes in hip position will affect flexion force at the knee. Therefore, proper stabilization and consistent positioning are critical for reliable and valid results.

Isometric Standardized Procedures

Isometric testing should involve contractions of four to five seconds duration with a one second transition period at the start of the contraction. At least one minute of rest should be provided between contractions. For each muscle tested at each position, at least three contractions should be performed although more may be performed if deemed necessary by the tester (e.g., due to improved performance over trials). If possible, the recorded force/torque should be sampled by a computer and averaged over time within each contraction. The optimal length of the averaging interval has not been determined.

ISOTONIC TESTING

Isotonic contractions refer to contractions in which an object of a fixed mass is lifted against gravity. Most types of weight training, either with machines or free weights, are referred to as isotonic. The derivation of the term isotonic means constant (iso-) tension (73), and is technically inaccurate since the force required to lift a weight changes throughout the range of motion. Other terms such as isoinertial (2,53,64) and DCER (dynamic constant external resistance (52) have been used to avoid the inaccuracy of the term isotonic. However, as the term isotonic is so ingrained in the language of exercise physiology, we argue that its use is acceptable provided that it is operationally defined as described above and is used consistently in that context.

Isotonic testing is typically performed on machines (e.g., Universal, Nautilus, Cybex) that incorporate adjustable weight stacks for resistance or with the use of free weights. The maximal amount of weight that can be lifted in one repetition is called the one-repetition maximum (1-RM), and is the most common measure of isotonic strength. Other measures such as the 3-RM, 5-RM, 10-RM, and the maximum number of repetitions that can be performed at a fixed resistance can also be determined. While scores on these tests are correlated with 1-RM, these measures are also affected by muscle fatigue and are not a measure of muscle strength per se.

The advantages of typical isotonic testing are that the necessary equipment is often readily available and, at least for free weights, is relatively inexpensive (52). In addition, since most resistance training programs emphasize isotonic training, isotonic testing is specific to the training that is typically performed. Further, isotonic testing has generally been reported to be reliable (2).

The primary criticism of isotonic testing is that the 1-RM strength score is limited by the weakest point in the range of motion (i.e., the so-called “sticking point”) (27,73). Therefore, the muscles used are performing sub-maximally during the range of motion at positions other than the sticking point. In addition, the 1-RM score does not provide information regarding the rate of force development or force output through the range of motion (63). Further, typical 1-RM testing provides a measure of concentric performance and no information about eccentric capability. Also, 1-RM lifts may not be specific to athletic events in terms of movement patterns, contraction velocities, and accelerations (2).

Isotonic testing of 1-RM involves a trial and error procedure in which progressively heavier weights are lifted until the weight exceeds the subject’s ability. Subsequent attempts are performed at a lower weight until the heaviest successful lift is determined. Because of the multiple trials involved, the testing can be confounded by fatigue (23) and a variety of factors need to be considered to optimize 1-RM performance. These include choice of starting weight, rest interval between attempts, increments in weight between attempts, use of feedback regarding weight to be lifted, and criteria for an acceptable lift. To date, there are no established standards for these decisions and little data are available to help discriminate between options. The following recommendations represent general procedures that have been employed in the literature (76,82,85) and which are consistent with physiological (e.g., recovery from fatigue) and safety considerations.

Isotonic Standardized Procedures

If the subject has experience with the isotonic lift to be performed, a good starting point is to have the subject estimate his/her maximum. From this estimate, desired percentages of the estimated 1-RM can be calculated. Similarly, if the subject knows the maximal number of repetitions that can be performed at a given weight, 1-RM can be predicted using the equations in the subsequent section entitled “Bench Press Prediction Equations.” The subject should perform a general warm-up of 3-5 minutes of light activity involving the muscle(s) to be tested (e.g., upper body ergometry prior to upper body strength testing). Next, the subject should perform static stretching exercises of the involved musculature. After the general warm-up, the subject should perform a specific warm-up set of 8 repetitions at approximately 50% of the estimated 1-RM followed by another set of 3 repetitions at 70% of the estimated 1-RM. Subsequent lifts are single repetitions of progressively heavier weights until failure. The initial increments in weight should be evenly spaced and adjusted such that at least two single lift sets are performed between the three repetition warm-up set and the estimated 1-RM. At failure, a weight approximately midway between the last successful and failed lift should be attempted. Repeat until the 1-RM is determined to the desired level of precision. The rest interval between sets should be not less than one and not more than five minutes (85). The optimal number of single repetitions ranges from three to five (52).

FIELD TESTS

Vertical Jump

The vertical jump (VJ) test is the primary test to assess muscular power in the legs. Unfortunately, there are a variety of procedures and types of VJ reported in different studies (37). There are two primary forms of the VJ test: the squat jump (SJ) and the counter-movement jump (CMJ). In the SJ, subjects lower themselves into a squat position and after a brief pause, jump upwards as quickly and as high as possible. No down motion is allowed immediately prior to jumping upwards. In contrast, in the CMJ subjects start in a standing position, drop to a squatting position (counter-movement), and with no pause jump upwards as high as possible from the bottom of the squat. In addition, both the SJ and CMJ can be performed with or without the use of arm motions. When arm motions are employed, the subject is instructed to thrust the arms forward and upward during the jump (75). When arm motions are not allowed, the subjects may be required to place their hands on their hips (3) or hold their hands behind their back (10).

The CMJ results in jump heights and power values that are higher than the SJ (10,75). For example, Sayer et al. (75) found CMJ jump heights that were 7% higher than SJ and peak power differences of 2.6%. Similarly, use of arm thrusts has been shown to significantly increase both SJ (10 cm.) and CMJ (11 cm.) performance (36). Indeed, the effect of arm motion exceeds that of the counter-movement. Currently, there is no consensus regarding whether arm thrusting should or should not be used during VJ testing. However, Sayers et al. (75) have argued that the SJ is preferred to the use of the CMJ for the following reasons. First, CMJ technique is more variable than SJ technique, as the extent of the counter-movement is not consistent across subjects. Second, regression equations used to predict peak power based on jump height and body mass are more accurate when using SJ data. Regardless of whether arm thrusts are allowed, or whether one uses the SJ or CMJ, the subjects need to be evaluated with the same procedures when tested repeatedly and the techniques used during the testing need to be considered when evaluating test data against published data.

When using the SJ, knee angle and foot position have been shown to affect performance. Martin and Stull (59) reported that optimal jump height occurred at knee angles of about 115° (as opposed to 90° and 65°) with the feet separated by about 5-10 inches laterally and 5 inches in the anterior-posterior direction. However, different studies have employed different knee joint angle requirements and some studies have let subjects determine their own knee angle starting position. As with arm thrusts, use of different starting positions can affect VJ performance and starting position needs to be consistent with repeated testing and should be considered when evaluating test data against published data.

The reliability of various VJ tests have been reported to be quite high (3,4,11,31,36). For example, Ashley and Weiss (4) found an intraclass correlation coefficient for a modified CMJ (no torso lean or arm swing) of 0.87 for repeated testing separated by 48 hours. Further, Arteaga et al., (3) found pooled coefficients of variation of 5.4% and 6.3% for SJ and CMJ scores (no arm thrusting was allowed) recorded during six test sessions over a 12 week period, suggesting that there is little variability or learning over time in these tests.

A great deal of variability exists in the literature regarding the warm-up and practice procedures employed during vertical jump testing. In untrained female subjects, Goodwin et al. (31) used three submaximal practice jumps prior to actual testing and found an ICC of 0.96 for repeated vertical jump testing. The change in the body center of mass was the dependent variable. These results suggest that three practice trials are sufficient to generate reliable vertical jump scores. In addition, Harman et al. (36) reported that three to five submaximal practice jumps were sufficient for untrained subjects to achieve peak jumping technique, although no data were presented to support this statement.

A variety of variables can be derived from the VJ. While direct measurement of power output requires the use of a force plate, estimates of muscular power can be made using prediction equations that incorporate vertical jump height and body mass (75). The Lewis formula has commonly been used to estimate power output during the VJ test, however the validity of this formula has been challenged (37). Recently, Sayers et al., (75) reported that the following equation, based on the SJ, resulted in an accurate prediction of muscular power:

$$\textit{peak power (watts)} = 60.7 \times \textit{(jump height [cm])} + 45.3 \times \textit{(body mass [kg.])} - 2055;$$
$$\textit{SEE} = 355\ \textit{watts}$$

For field-testing, use of the Sayers equation is straightforward and requires only the ability to record body mass and VJ height. To record VJ height, two procedures are primarily used. First, subjects may simply place chalk on their fingers and mark a wall as they reach the top of the jump. The difference between the mark at the height of the jump and a mark from the fingertips at full extension while standing is recorded as the VJ height (37). Second, commercial devices have been developed that record jump height (4). These devices have a vertical pole with a series of horizontally oriented metal rods that are free to rotate about vertical when hit by the fingers. VJ height is based on the highest pin that is moved at the top of the jump.

With respect to specific testing of the VJ, either the SJ or the CMJ may be employed, however the SJ is preferred. Use of the equation of Sayers et al. (75) should be used to estimate muscular power from jump height. At least three practice trials should be employed prior to recording test performance. Jump height can be determined using either chalk marks on a wall or by using a commercial device. With repeated testing, it is vital that use or non-use of arm thrusts be held constant and that for the SJ, the knee angle at the start of the motion be consistent.

Bench Press Prediction Equations

The one-repetition maximum (1-RM) is the standard for determining isotonic strength. However, determining 1-RM values for large groups of individuals is very time consuming. For example, Chapman et al. (24) noted that when testing 98 football players for the 1-RM bench press, three testers were required over six hours of testing and five testing stations were employed. In addition, it has been suggested that 1-RM testing may expose those being tested to increased injury risk (24). Therefore, the use of single set tests in which 1-RM values are predicted based on the number of repetitions performed with a submaximal weight have been used. These types of tests can markedly decrease the time involved in mass testing (24). In contrast to the six hours and three testers required for the testing of the 98 football players described above, only one tester and 2.5 hours were required to test the same subjects using a test in which the maximal number of repetitions that were capable of being performed in a single set was determined. It should be noted however, that there are no data to indicate that these tests are safer than typical 1-RM testing.

The most common exercise to which submaximal isotonic testing has been applied is the bench press, and will be the focus of this section. Two types of 1-RM prediction tests have been developed. In the first type, subjects perform the most repetitions that they can at a load that is some percentage of their estimated 1-RM (relative load test). Alternatively, all subjects can be tested at the same load (absolute load test). The most common absolute load test involves performing the maximum number of repetitions possible at a load of 225 pounds. Because this test is frequently used in the National Football League, it has been called the NFL-225 Test (62), however it is also used with collegiate and high school athletes.

A variety of papers have been published reporting 1-RM bench press prediction equations based on relative load tests, and many of these have been evaluated by LeSuer et al. (57). In brief, seven prediction equations were cross-validated with a sample of 67 college students (27 females). For the bench press, the equations derived from Mayhew et al., (61) ($1\text{-}RM = 100 \times rep\ mass/(52.2 + 41.9 \times exp\ [-0.055 \times reps])$, $r^2 = 0.98$, mean difference between predicted and actual 1-RM = 0.5±3.6 kg) and Wathen (83) ($1\text{-}RM = 100 \times rep\ mass / (48.8 + 53.8 \times exp\ [-0.075 \times reps])$, $r^2 = 0.98$, mean difference between predicted and actual 1-RM = 0.5±3.5 kg) were reported to most accurately predict the 1-RM bench press. The submaximal load used during the test of the maximal number of repetitions was chosen based on subject experience to be a load that would cause fatigue (failure) within 10 or fewer repetitions. Another study (47) also found that the Wathen equation resulted in predicted 1-RM values that were closest to the actual 1-RM in a variety of upper body exercises in elderly subjects. Of note is that these equations require only the recording of the mass lifted and the number of repetitions performed. Gender appears to have little effect on the accuracy of the prediction equations (61), indicating that a common regression equation can be used for both males and females. Similarly, adding anthropometric variables to regression equations seems to add little to the predictive ability of the equations (26).

The absolute load NFL-225 Test has also been shown to accurately predict 1-RM bench press strength (24, 62). The work of Mayhew et al. (62) resulted in a cross-validated prediction equation as follows:

$$1\text{-}RM\ (lbs) = 226.7 + 7.1\ (\#\ reps);\ SEE = 14.1\ lbs.$$

To date, this equation represents the best prediction equation available for predicting 1-RM bench press from an absolute load test. Two caveats are worth noting however. First, this test is only effective in subjects whose 1-RM bench press is at least 225 pounds, and therefore may have limited utility in testing weaker subjects. Second, the accuracy of the equation decreases as the number of repetitions increase beyond 10 (24,62), which limits its effectiveness in very strong subjects.

With respect to specific use of submaximal tests to predict 1-RM bench press performance, both relative load and absolute tests can be used. If using a relative load test, the equation of Mayhew et al. (61) or Wathen (83) are recommended. If using the NFL-225 test, the equation of Mayhew et al. (62) is recommended. In addition, the NFL-225 test can only be used with subjects whose 1-RM bench press is ≥ 225 pounds.

Wingate Anaerobic Cycle Test (WAT)

This test is intended to measure anaerobic power of the lower body. It is an exhausting test that should be used with a population accustomed to strenuous vigorous exercise. The resulting data is an indirect measure the ability of a subject's lower body to produce high levels of power. Test results are divided into six equal periods of 5-s where **peak power**, in Watts, is the highest average power output during any one 5-s period and **mean power** is the mean of all six 5-s periods. **Fatigue percentage** is the difference between peak power and the power from the lowest 5-s period. Normative values for this test have been published in the literature (41, 60).

Reliability and Validity

Test re-test reliability of the WAT has generally been reported to be higher than r=0.94 (38, 42). Validity of the WAT is difficult to measure since there is no universally accepted "Gold Standard" of anaerobic measurement. However, laboratory studies have been performed comparing the WAT and field tests of anaerobic power. Moderate correlations with the WAT have been demonstrated between short explosive field measures such as the vertical jump (mean power r=0.74) (78), 50 yard run time (relative mean power r=0.69) (78), Margaria-step-test (peak power r=0.79) (5) and multiple repetition isokinetic testing (mean power r=0.78) (42). In addition, the relative percentage of fast twitch fiber type of the legs has shown moderate correlations (relative peak power r=0.60) (9).

Resistance

One of the most difficult questions to answer when administering the WAT is what resistance setting to use. The classic resistance (in kiloponds; kp) is determined by multiplying the subject's body weight in kilograms (kg) by the constant 0.075 (8,60). While 0.075 kp/kg of body weight appears to work well for sedentary adults (5), subsequent research has demonstrated that this may not be the optimal setting for other populations (69,28). In addition, mean power and peak power require different settings for optimization (28) due to the force/velocity and power/velocity relationships discussed later. The optimal force/velocity relationship when pedaling has been reported to be approximately 100 rev/min (28). Therefore, it is recommended that non-athletes use a force of 0.090 kp/kg and athletes use a force of 0.100 kp/kg (41).

Standardized Procedures

During testing, the subject is asked to pedal against a pre-selected opposing resistance at the maximum pedal rate possible for 30 s. A Monark cycle ergometer is most commonly used for testing. The ergometer should be calibrated before each test, using standard calibration weights, throughout the full range of the pendulum. A computerized Wingate testing system (Sports Medicine Industries, Inc., St. Cloud, MN) is available that counts ergometer flywheel revolutions. Briefly, in consists of an optical sensor, attached to the ergometer frame, which notes the passage of reflective markers on the ergometer flywheel at 10 cm intervals. A microprocessor then converts these signals to rev/s.

The subject's saddle height is adjusted to produce five to ten degrees of knee flexion when the foot is at the bottom dead center position. Warm-up should include 2-3 minutes of cycling at 1 to 2 kp with several all out bursts interspersed. Resistance is set at the end of the warm-up period by asking the subject to pedal into the increasing resistance. When the correct resistance is established the subject is instructed to stop pedaling. The test procedures are then reviewed with the participant. The test begins with a free wheeling start as the participant pedals as fast as possible with no resistance. The resistance is then either dropped instantly or ramped up as quickly as possible. If a ramping protocol is used, the first two seconds of the test (when the subject overcomes the inertia of the initial resistance) should be excluded from data analysis. This action coincides with the activation of the microprocessor. Pendular oscillations at the onset of the test, outside the pre-determined opposing resistance, should be minimized through manual restriction. Feedback concerning elapsed time is given at 10, 15, 20, 25 and 30-s, with 30-s followed immediately by the command "STOP". Consistent verbal encouragement is provided during the test but no visual feedback should be used. Following the "STOP" command, the resistance is decreased and the subject cools down at a self-paced cadence to reduce venous pooling in the legs.

Margaria Stair-Run Test

This is a short-term explosive power test that requires stair climbing. Since this test requires the participant to climb the stairs two at a time it may not lend itself to use with a young undersized population. Power on the Margaria test has displayed a moderate correlation (r=0.74) with mean power of the Wingate cycle test representing adequate validity of anaerobic power (69).

Standardized Procedures

The test requires a staircase and two electronic switch mats interfaced with a digital time clock capable of recording to one 100th of a second. The mats are placed on the 8th and 12th steps and step height should be approximately 6.9 inches.

The subject begins approximately six feet (two meters) from the first step and is instructed to run at top speed towards the stairs. Upon reaching the staircase, the subject should negotiate the steps two at a time until passing the second switch mat. The mats will correspond to the fourth and sixth steps taken. Power (P expressed in Watts) is then derived from the following formula:

$$P = (W \times 9.8 \times D)/T$$

where W = bodyweight of the subject in kg, 9.8 = acceleration of gravity in meters per second^2, D = vertical height (in meters) traveled between switch mats one and two, and T = elapsed time (in seconds) between switch mats one and two. Increasing the approach distance (six and ten meters) has been shown to increase power significantly (40).

ISOKINETIC TESTING

Isokinetic exercise is by definition constant velocity and represents a match between mechanically imposed velocity and the subject's movement (e.g., knee extension). The reliability of isokinetic testing has been measured repeatedly (13,77,80) and found to be high. However, a variety of factors need to be controlled or accounted for in order to generate reliable and valid data. These include factors such as choice of variable measured (e.g., peak torque, work, or power), proper positioning and stabilization, and data reduction procedures (e.g., windowing). The following will delineate confounding elements that may impact velocity specific tests and focus on standardized testing procedures that should be considered when utilizing an isokinetic device.

Peak Torque, Work, and Power

A wide range of performance variables are available for isokinetic data analysis. Of these, three are particularly important for strength and power testing. Peak torque is defined as the product of mass, acceleration and lever arm length. It is the maximum torque produced anywhere in the ROM and is easily identified as the top of the torque curve (i.e. graphic display of dynamic torque vs. position). As such, peak torque is analogous to the isotonic 1RM discussed earlier and exhibits an inverse relationship with velocity. While peak torque provides the exercise professional with information regarding the greatest torque output of the limb tested, and is an excellent indicator of the subject's maximum strength level, it does not take into account ROM.

Rotational work is defined as the product of torque and distance traveled and is most easily computed as the area under the torque curve. Since work accounts for distance traveled it reveals a subject's ability to produce torque throughout the ROM. Like torque, work is inversely related to velocity. Power may be the most encompassing variable as it accounts for torque, distance and time. Power is defined as the work/time quotient and demonstrates a parabolic relationship with velocity.

Strictly speaking, peak torque is a measure of an individual's maximum strength while work assesses their ability to sustain torque output across a limb's ROM. Power, since it utilizes time in the equation, may be best described as one's ability to express explosive strength. Each variable communicates strength in a slightly different manner and should be used judiciously regarding intended outcomes.

Isolation and Stabilization

Isolation in its simplest form is merely testing one muscle group alone with the exclusion of any other group adding to the test outcome. This is best achieved through proper positioning and strapping (i.e. stabilization) of the subject in the dynamometer. Using knee extension as an example, isolation occurs through the utilization of waist and thigh stabilization. The purpose is to restrict motion to knee extension and flexion without extraneous joint movement about the hip. This will insure that only the quadriceps and hamstring muscle groups are producing torque through the dynamometer. For example, Weir and colleagues (84), measuring knee extension torque at 60, 180 and 300 °/s with stabilized and non-stabilized conditions, have shown that extraneous movements may reduce torque output and change the angle of peak torque production secondary to changes in muscle length. This same potential error is present at all joints if care is not taken to control for extraneous movement. For example, shoulder internal/external rotation torque may be inflated through the addition of trunk rotation torque if proper stabilization of the torso is not achieved.

Axis of motion

Each dynamometer on the market consists of a lever arm attached to a dynamometer head. Resultant muscle torque is recorded at this juncture through rotation of the lever. It is critical that the axis of rotation of the machine and the joint being tested are aligned. If the lever axis and the joint axis are not in alignment, torque measurements will be invalid. Rothstein (72) and colleagues make a cogent argument for the use of aligned axis of rotation by stating that errors associated with misalignment may be amplified in joints where the axis changes with movement. The knee and shoulder are such joints. They further state that since the axis of the machine is stable any joint with uncontrolled movement will result in measurement error.

Gravity compensation

Since exercise on an isokinetic device is most often performed in a gravity environment, special consideration must be taken to account for its effects. Using seated knee extension/flexion as an example, one can see that performing a knee extension movement requires an individual to lift the weight of their limb and the dynamometers lever arm against gravity. However, during seated knee flexion, gravity assists the motion by pulling down on the limb and lever. In this scenario, flexion torque may be artificially inflated due to gravity while the opposite is true for extension.

Without compensating for the effects of gravity the test results are subject to large errors. Winter (89) and colleagues documented mechanical work errors ranging from 26% to over 500% during knee extension and flexion exercise at 60 and 150 d/s.

Range of motion

Both physiologic and total range of motion (ROM) need to be considered when performing exercise on a dynamometer. These are operationally defined as follows: physiologic ROM is the anatomical beginning and end of the movement while the total ROM is the arc traveled through the physiologic ROM. For example, shoulder motion from zero to 90 degrees and from 90 to 180 degrees of flexion both have the same total ROM (90 degrees) but very different physiologic ROM. Since the physiologic ROM affects muscle length and joint moment arms**,** it follows that valid comparisons of torque production must be consistent with respect to physiologic ROM. Similarly**,** errors associated with ROM measurements may be magnified when interpreting work and power variables. Since work is the product of torque and distance ($W=TxD$) and power is a function of work and time ($P=W/T$), distance traveled must be precise for comparative purposes. By setting hard stops at each end of the ROM, the practitioner can insure that all between and within subject comparisons involve the same physiologic and total ROM.

Standardization of Instructions

Any instructions given to the subject should be consistent from one test to the next and from one subject to another. Not all individuals respond to the same form of verbal encouragement. Therefore, instructions should be concise and parsimonious. Furthermore, since the dynamometer is a unique piece of equipment it may not be familiar to most subjects. This unfamiliarity may cause anxiety in some subjects and lead to misunderstandings regarding test procedures. Therefore, verbal commands should be explicit as to every facet of the procedure. This includes, but is not limited to, where to grasp the attachment, how to breath, what to do with the contralateral limb, how to push in both directions, how to give a maximal effort, what constitutes one full repetition (e.g. extension and flexion) and how many repetitions to perform.

Practice

Analogous to verbal commands for proper instruction is sufficient practice repetitions. Since the dynamometer is novel to most subjects, they may require several practice trials in order to achieve reliable torque tracings. It is recommended that one perform as many repetitions as needed to completely understand what is required during the testing or training process. This may be as few as three for experienced resistance trained individuals or as many as 15 for naive subjects.

Repetitions

Choosing the number of repetitions to include in a test is determined by what information is desired from the test or what outcome from the exercise session. For strength testing there is no need to perform greater than five repetitions but one may choose to perform as many as 50 repetitions when endurance is of interest.

Placing a limb in a pre-activated state (i.e. neural activation prior to movement) has been shown to significantly affect strength variables. Neural pre-activation of muscle units in the exercising limb place that limb in a ready state which in turn leads to greater torque production. Kovaleski and colleagues (49), using knee extension at 120 through 210 °/s, have documented the use of pre-load (prior neural activation) as superior to isokinetic training and may afford individuals full ROM strength development based on a reduced acceleration range. Additionally, the first repetition (beginning from a dead stop without a prior antagonistic muscle action) has been shown to result in larger areas of acceleration prior to the constant velocity phase (18). Therefore, the first repetition (of five) during strength testing may be discarded from data analysis as all subsequent repetitions are immediately preceded by a pre-activation state.

Velocity order

Many dynamometers on the market today have a velocity range between 0 and 500 degrees per second (°/s). The practitioner must decide which speed to use for testing or training depending on the desired result. When testing at multiple speeds it may be beneficial to randomize the sequence in order to control for order effects. However, there is conflicting evidence regarding whether velocity order significantly affects strength variables such as peak torque, work and power. Timm and Fyke (80) have shown no significant difference in torque measurements of knee extension at 60, 180 and 300 °/s when varying test speed sequence. However, Kovaleski and Heitman (48,50,51) have shown velocity progression order to play a role in torque, work and power production during knee extension at 30 through 210 °/s. The major difference between these seemingly opposing views appears to be number of repetitions performed. While Timm (80) performed only five repetitions, Kovaleski and Heitman (48,50,51) performed 10. Therefore, fatigue may have been a factor in the latter studies and rest intervals may need to be adjusted accordingly.

Bilateral Deficit

Dynamometers can be modified to test both limbs simultaneously (14,15,16). When testing or training is performed in this manner, the practitioner should be aware of the bilateral deficit phenomenon. That is, when two limbs are performing maximal muscle actions simultaneously the resultant torque will be less than the sum of the individual limbs tested in isolation. Brown and colleagues (14,16) have reported that females may show a decrease in the bilateral deficit with increasing velocity from 60 through 360 °/s, which may be explained through decreased activation of primarily slow-twitch muscle fibers (14,16). They have also shown significant torque improvements unilaterally following bilateral training of the knee extensors and flexors at 60 and 180 °/s (14) along with a decrease in the bilateral deficit with increasing velocity.

Load Range

It has been demonstrated many times (17,18,19,32,33,56,66,67,68) that isokinetic devices, despite their claims of isokinetic movement, are not truly isokinetic. Exercise on an isokinetic device involves three main phases of movement: acceleration, constant velocity and deceleration. Inherent in these phases are unique occurrences that may confound test data and thereby test interpretation (1,6,12). However, the acceleration phase, which is spent "catching" or matching the isokinetic velocity, is done without resistance from the dynamometer. In other words, there is a portion of the available ROM during which there is no quantifiable external load. The ROM with external load or that ROM when there is a match between isokinetic velocity and limb movement is referred to as load range. Load range becomes increasingly smaller as velocity is increased (17,18,19,56,66,67,68). The work of Osternig and colleagues (66,67,68) first showed this inverse relationship. They detailed load range decreases from 92% to 16% at isokinetic speeds from 50 to 400 °/s.

Practically, this means that as the pre-selected velocity of an isokinetic device is increased an exercising individual receives external overload through an ever-decreasing portion of the full ROM. Couple this effect with the fact that torque is inversely related to velocity and the result is short-arc low-resistance exercise at high speeds with the remaining ROM as acceleration or deceleration. In other words, exercise on an isokinetic device at high velocities is primarily attempting to reach the pre-determined speed (accelerate and catch the lever arm) or slow down prior to contacting the end stop (decelerate). Thus, acceleration and deceleration should not be considered during test interpretation. However, data from these phases are often included in analysis and may result in erroneous conclusions.

Specific errors associated with artifacts in the non-load range portions of the repetition have been identified and will be examined in the sections below. Taylor et al. (77) documented increased errors with increased velocity from 60 to 450 °/s and cautions against ascribing artifact torque to the exercising limb. Tis and Perrin (81) caution that using a data reduction technique that eliminates the first and last 10 degrees of ROM may eliminate acceleration and deceleration areas but may also eliminate the peak torque range.

Velocity Overshoot and Torque Overshoot

Prior to the limb receiving machine resistance it must pass through a free acceleration phase (74). Upon engagement of the resistance portion (load range) there are artifacts manifested in the torque tracings. Immediately following the acceleration phase of motion the lever arm and attached limb exhibit speed that is greater than the pre-selected velocity by as much as 200% (70,74,81). This is followed by the dynamometer's attempt at slowing the limb via a braking mechanism inside the power-head. Velocity overshoot occurs as a function of the limb accelerating past the desired speed. The subsequent braking results in an obvious torque spike as it slows the limb to the pre-selected velocity. The effect of this braking is mild at slow speeds such as 60 °/s but increases in magnitude with increased velocity. Velocity and torque overshoot are coincident at the beginning of the flat load range.

This resultant torque overshoot is caused by the preceding velocity overshoot. As mentioned earlier this spike will grow with increasing velocity as the braking mechanism of the dynamometer must account for ever increasing amounts of velocity overshoot. The torque spike may dwarf actual peak torque produced by the human muscle. Obviously, it is important to remove this artifact prior to test interpretation. At present no dynamometer on the market will automatically remove torque overshoot so the practitioner must recognize the artifact and not consider it during analysis. However, some dynamometer systems (e.g., Biodex) attempt to control these effects by using a data reduction technique called windowing (87). During windowed analysis the acceleration and deceleration phases of the repetition are eliminated and only the load range data is preserved. This technique has been shown to increase the reliability of testing via the control of aberrant torque production (87).

Lever arm oscillation

Another artifact inherent in the torque tracing is oscillation. This occurs immediately following torque overshoot (25,74). Just after the acceleration phase there is a period of lever arm oscillation that is a function of the length of the lever and the braking procedure to counteract velocity overshoot. The exercising limb is attached to the dynamometer lever arm shaft distally but produces torque proximally and may therefore be thought of as analogous to a long fishing pole. If one grasps a fishing pole at one end and applies a quick whipping motion the distal end will oscillate back and forth for a short period of time until stabilized. Greater oscillation occurs with greater lever arm length and greater velocities as the distal end attempts to "catch up" and then decelerate to the speed of the proximal end (25,74). The probability of error is increased with the inclusion of lever arm artifacts such as these as it may be impossible to determine actual torque measurements apart from extraneous data. As with torque overshoot, windowing the data may remove some of the erroneous data.

Impact Artifact and Isometric Spikes

At the other end of the repetition from acceleration is deceleration that culminates in the stopping of the lever arm. Many of the confounding elements already mentioned during the acceleration phase occur in reverse order during deceleration. The dynamometer begins to slow the lever arm in anticipation of stopping at the turn around point. This causes the lever arm to oscillate somewhat and ultimately results in a large isometric spike at the end of the repetition due to the lever arm impacting the mechanical end stop (89). The spike is greater with increasing velocity, since the limb and lever are moving much faster upon impact. These spikes can be as much as twice as great as the torque seen during load range and should not be confused with actual muscle torque production (12,72,77,87).

Isokinetic Standardized Procedures

First position the dynamometer shaft so that it is aligned with the assumed axis of rotation of the joint being tested. The subject is in either a seated or lying position with the back incline noted on a permanent measurement scale. The contralateral limb is secured with straps as is the waist and torso. Arms and legs not in use are either secured with or grasping the straps. Range of motion mechanical stops are set at the beginning and end of the desired test ROM. The lever arm pad is positioned to place the inferior aspect immediately superior to the most distal point on the limb. Warm-up on the isokinetic device consists of three submaximal reciprocal concentric extension and flexion repetitions with increasing intensity (i.e. first repetition at 25% perceived effort, second repetition at 50% perceived effort, etc.) at the slowest through the fastest speed (13,80). In addition each subject completes two maximal intensity repetitions at each speed, then rests for one minute prior to testing. More practice repetitions may be performed if the subject is not comfortable with the test.

Strength and power testing begin from a dead stop with the subjects' limb at one end of the ROM and consist of five maximal concentric reciprocal extension and flexion gravity corrected repetitions with 30-s rest between velocities (80). Each subject is encouraged to contact the mechanical end stops during both extension and flexion motions. Consistent and identical verbal encouragement is provided during the test but no visual feedback of torque generation is provided. The first and last repetitions are discarded, using only the three middle reps for analysis, and all data are windowed to eliminate extraneous information as already discussed.

Repetition data is then reduced to strength variables such as peak torque (maximum value), mean torque (average across all repetitions), total work (max product of torque and distance) or average work (average product of torque and distance) and expressed in foot-pounds (ft/lbs) or Newton-meters (Nm). Average power (torque/time quotient) and instantaneous power (product of torque and velocity) are expressed in Watts.

Force and Power/Velocity Curves

The interaction of velocity and human force production has been known for some time. Ever since Hill (34) established the inverse relationship between force and velocity for concentric muscle actions, human beings have tried to alter the curve through training and muscular adaptation. Likewise, the parabolic relationship between power and velocity (44) has sport specific diagnostic and predictive value. In the case of isokinetic dynamometry the force is rotational and therefore properly referred to as torque.

Since the overall shape of both the torque/velocity and power/velocity curves are well established, it is a simple task to gather this information from individual subjects utilizing an isokinetic dynamometer capable of measuring velocity specific torque and power. The data can then be used for comparison purposes between athletes or as a baseline for future testing. The procedure is to perform a maximum torque test across a velocity spectrum beginning at 60 °/s, and increasing the velocity by 60 °/s until the maximum velocity of the machine (e.g.,400-500 °/s) or the individual has been met. As previously explained, it is very important to ensure that data are evaluated only during the load range portion, as this will prevent the inclusion of extraneous artifacts.

Previous work (19) has shown that males and females display disparate levels of maximum attainable velocity on this apparatus. Therefore the curves should be evaluated by gender. Figures 1 and 2 represent gender specific data from our laboratory that are representative of strength/velocity relationships in college age subjects. Note that not only do the absolute values of males exceed females but also the shapes of the curves are different. The torque/velocity curve (Figure 1) of males is steeper than females and peak power (Figure 2) occurs later in the velocity spectrum for males (240 °/s) when compared to females (180 °/s). While this may be partially explained as a function of muscle mass there is evidence of underlying neural differences between genders (46) that may further explain the disparity.

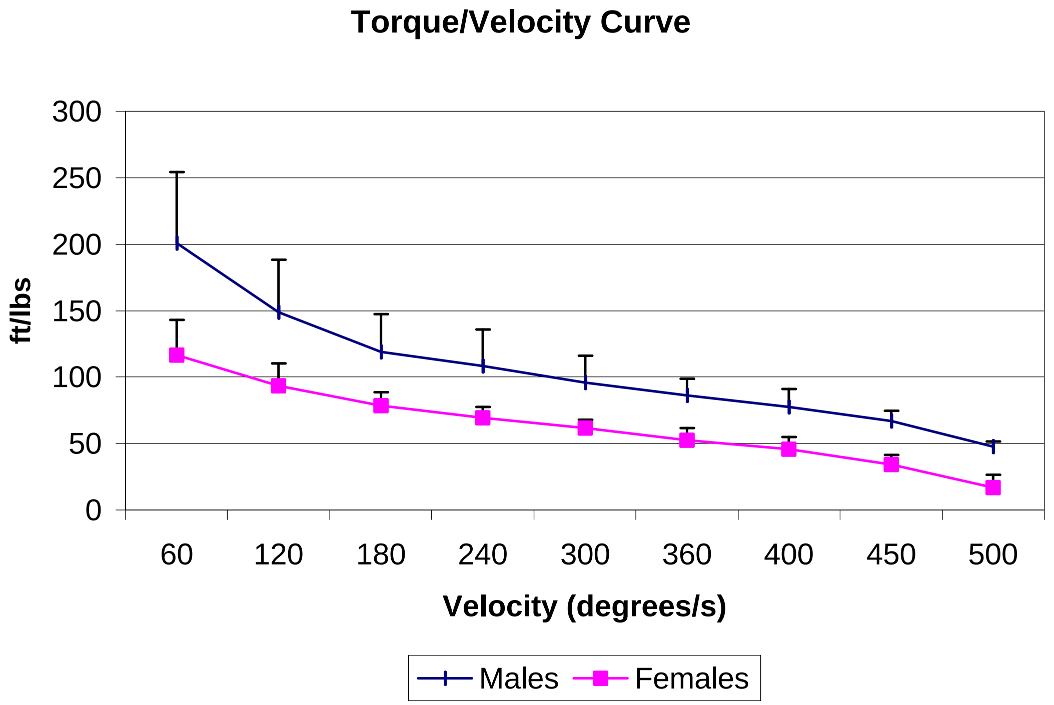

Figure 1. Concentric torque/velocity curve by gender measured on a Biodex System 3 Isokinetic Dynamometer.

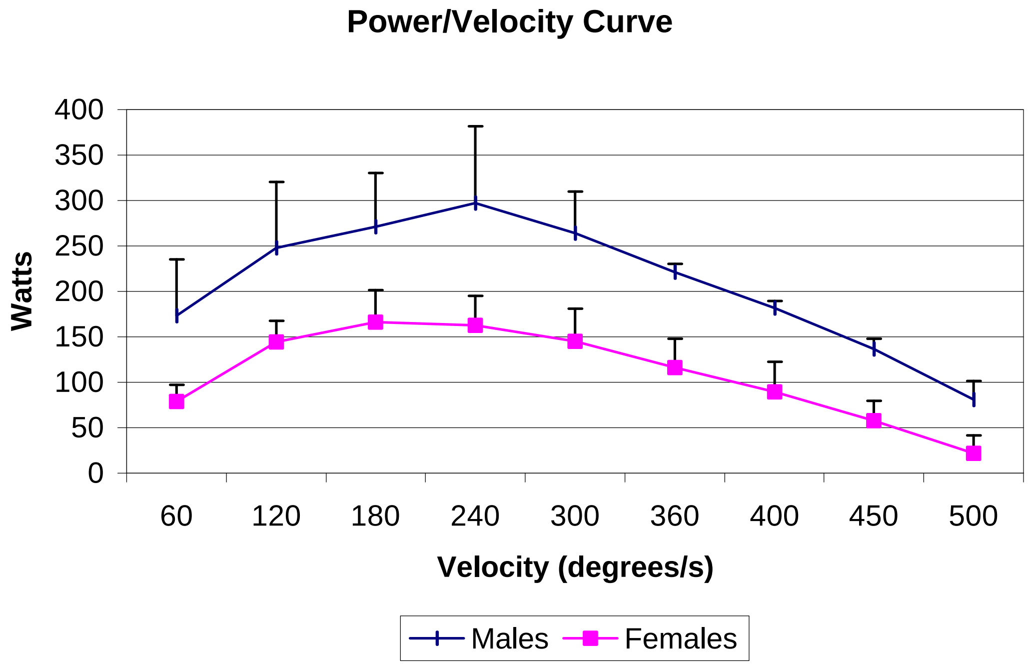

Figure 2. Concentric power/velocity curve by gender measured on a Biodex System 3 Isokinetic Dynamometer.

Multiple Repetition Testing

Any discussion of adaptations associated with training stimuli must include individual differences in limb musculature and fiber type that predispose some subjects to reach greater gains in strength relative to inherent force/velocity or power/velocity characteristics.

Thorstensson (79) hypothesized that muscle quality plays a major role in strength expression. To test his hypothesis Thorstensson took muscle biopsy samples from the vastus lateralis of 25 trained male subjects between the ages of 20 and 30 years and stained them for slow twitch (ST) and fast twitch (FT) fiber type. He then recorded maximal velocity of knee extension motions in an unloaded state and tested for peak torque isometrically and isokinetically at 180 °/s. Strength test results were not different between individuals with low and high percentages of FT muscle fibers when compared isometrically. However, when maximal velocity was measured, significant differences became apparent. That is, subjects with a higher percentage of FT fibers exhibited greater maximum velocity and strength with a positive correlation of $r=0.75$ between peak torque at 180 °/s and percentage FT fibers. It was concluded that a high proportion of FT muscle fibers would be advantageous for high force output at fast motion velocities requisite for success in sport specific activities. Wickiewicz and colleagues (86) studied the relationship between muscle architecture and the force-velocity curve in 12 subjects who performed isokinetic knee extension strength at velocities ranging from 0 to 300 °/s. Comparisons were then made with muscle samples of cadavers for linear displacement of muscle fibers and architectural data. The results showed that greatest torque at high velocities was related to fast twitch fibers and the number of fibers in series. Specifically, individuals with longer sarcomeres displayed less torque reduction at fast velocities while subjects with a larger muscle cross sectional area exhibited the greatest torque outputs at slow velocities.

Houston (39) examined the relationship between muscle fiber composition and maximal acceleration and torque capabilities of the knee extensors in 27 subjects using an unloaded apparatus that did not restrict limb motion. Muscle fiber composition was attained from the vastus lateralis of each subject using needle biopsy techniques and compared to electromyographic and performance measures during knee extension movements. Positive correlations between peak velocity and acceleration ($r=0.69$) were found, as well as acceleration and fast twitch fiber percentage ($r=0.4$) with a trend toward a positive correlation between acceleration and fast twitch area. Gender comparisons demonstrated that the electromechanical delay (time lag between the onset of electrical neural activity and the beginning of acceleration) was similar for males and females. However, males produced significantly greater force output than females evidencing a neural bias towards males.

In an experiment in our laboratory (15), following the protocol of Thorstensson, we compared the Wingate cycle ergometry test with an bilateral isokinetic test of power and found significant correlations between the two tests for peak power ($r=0.84$) and mean power ($r=0.54$) but not fatigue percentage ($r=0.37$). Wingate peak power and mean power were significantly greater ($p<0.05$) than isokinetic values while fatigue percentage was not statistically different between tests. Males exhibited significantly greater values across all variables when compared to females with the exception of Wingate fatigue percentage. It was concluded that the bilateral isokinetic test of power revealed a significant power profile with the cycle ergometry power test.

Multiple Repetition Procedures

The above information points to the ability to estimate an individual's fiber type from isokinetic strength and power tests. Specifically, the procedures for the Thorstensson multiple repetition assessment will yield fatigue percentage of the quadriceps. This can be used to estimate the relative percentage of fast twitch fibers (%FT) of the vastus lateralis. Subject physical set-up on the isokinetic dynamometer is identical to that discussed earlier. The velocity should be pre-set to 180 °/s and the ROM limited from 90 degrees of knee flexion to 0 degrees of extension (horizontal). The test consists of 50 maximal knee extension repetitions with a passive return to 90 degrees (no hamstring activity).

Determine the average peak torque of repetitions 1-3 and repetitions 48-50. Subtract the average of repetitions 48-50 from repetitions 1-3 then divide by the average of repetitions 1-3 then multiply by 100. The answer (fatigue percentage, FP) should then be inserted into Thorstensson's formula which will yield percent fast twitch.

$$0.9 \times (FP) + 5.2 = \%FT \ (r=0.86, p<0.01)$$

SUMMARY

Care must be taken to insure proper use of any strength testing equipment and interpretation of data. The practitioner should be aware of standardized testing procedures such as proper warm-up, safety (including emergencies) and rest periods, isolation and stabilization of subjects and muscle groups as well as proper axial alignment of the individual and the apparatus. Instructions should be clear and identical across subjects and each participant should be afforded the opportunity to become completely familiarized with the procedure and the apparatus prior to data collection.

A suitable plan should be in place detailing what information is desired from the test combined with the knowledge of the specificity of strength and power results secondary to mode, procedure and apparatus. Tables one and two identify possible choices of tests that are specific to a desired outcome.

Table 1. Recommendations for Specific Strength Tests and Outcomes

Desired Outcome	*Specific Test*
1. Lower body strength	1RM Squat
2. Upper body strength	1RM bench press
3. Angle specific torque	Isometric
4. Individual muscle torque	Isokinetic five reps
5. Muscle Group torque	Isotonic 1RM

Table 2. Recommendations for Specific Power Tests and Outcomes

Desired Outcome	*Specific Test*
1. Lower body	Vertical jump/Margaria
2. Upper body endurance	Bench press for reps
3. Anaerobic endurance	Wingate cycle
4. Muscle fiber type	Isokinetic multiple repetition

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