Advances in Rehabilitation and Performance Testing

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Specialized testing procedures allow rehabilitation clinicians and strength and conditioning specialists to measure progress and functional level. Testing will ensure a safe progression throughout the rehabilitative course by providing the needed criteria for advancement. Performance testing quantifies the pure physical nature of athletic performance. Successful rehabilitation can be attained only by following a functional progression. Testing procedures also follow a progression, which begins with basic measures and progresses to functional tests of increasing difficulty that include sports-specific testing before returning to field play. Clinical tests provide both quantitative and qualitative information. These tests not only quantify physiologic response to rehabilitation but also allow the clinician to provide qualitative feedback to an individual during a specific activity. Balance, strength, power, cardiovascular endurance, functional movement, as well as the component of apprehension with sport-specific activity are important and valuable measures in prevention, rehabilitation, and performance programs.

Rehabilitation clinicians and strength and conditioning specialists are vital to an athlete during rehabilitation after an injury or when training to enhance his or her competitive performance. Rehabilitation clinicians serve to prepare an athlete for return to sport after injury. Strength and conditioning specialists serve to improve an athlete’s physical performance by providing a sports-specific individualized fitness program. The use of specialized testing procedures allows these professionals to measure progress and functional level.

Rehabilitation testing will ensure a safe progression throughout the rehabilitative course by providing the necessary criteria for advancement. Performance testing quantifies the pure physical nature of athletic performance. Performance in any sport is determined by the athlete’s technical, tactical, physiologic, and psychosocial characteristics. Rehabilitation clinicians and strength and conditioning specialists should...
be familiar with current practices and standardizations of tests and measures to provide an accurate prediction model for the successful return of an athlete to his or her sport. These tests and measures encompass a vast array of skill sets and body systems. This article discusses the most recent advances in rehabilitation and performance testing, which use updated approaches and thought processes in their design.

Successful rehabilitation can be attained only by following a functional progression. Kegerreis² has defined a functional progression as “an ordered sequence of activities enabling the acquisition or reacquisition of skills required for the safe, effective performance of athletic endeavors.” To ensure adherence to this concept, graded testing procedures should be employed. Davies describes a functional testing algorithm (FTA) (Table 1) that begins with basic measures and progresses to functional tests of increasing difficulty, which include sports-specific testing before returning to field play.³ The progression model is designed to increase the stresses placed on the athlete by providing different functional testing maneuvers, which require an increase in motor control. These tests can be performed in the clinic beginning with basic functional movements.

On successful completion of the clinical tests and clearance from the referring physician, the athlete may progress to a pre-participation examination that consists of sports-specific field tests. These tests incorporate sport specific movements and are aligned with the skill set needed for participation in a particular sport. The athlete’s sport and his/her specialty within that sport will determine the testing procedures that are used.

Within the FTA progression model, clinical tests address both qualitative and quantitative data. Qualitative data are defined as the attributes of movement during a particular task, whereas quantitative data are defined as numerical results obtained from a given test measurement. In recent years, clinicians have accepted the importance of functional training. Many clinicians have modified the rehabilitation model to focus on more than just pure isolated movement exercises.⁴ The improvement in the quality of movement will increase the efficiency of the athletic movement and thus carry over onto the playing field. Therefore, a new approach to performance testing that includes the standardization of qualitative data should be used.

Obtaining quantitative data is inherent and necessary in athletic endeavors. The standardized data that quantitative tests produce are applicable at tryouts or combines when comparing the performance of athletes. They also provide a way to make comparisons between norms to determine an athlete’s level of fitness or categorize athletic potential. In the clinical setting, standardized tests help to diagnose specific areas of weakness that may not be detectable with remedial testing.

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procedures. For example, the sensitivity of isokinetic dynamometry allows identification of changes in muscular power and strength between limbs, which may have been otherwise undetectable by basic manual muscle testing techniques. These data can then be used to guide recommendations for return to sport or determine the next progressions in a rehabilitation program.

**CLINICAL TESTS FOR REHABILITATION PROGRESSION**

As previously discussed, clinical tests provide information regarding the level of progression the athlete has obtained within the rehabilitative process. Clinical tests also provide feedback to an athlete by identifying specific physical impairments. These tests must not only quantify physiologic response to rehabilitation but also allow the clinician to provide qualitative feedback to an individual during a specific activity.

**BALANCE**

Balance has been defined as the process of maintaining the center of gravity (COG) within the body’s base of support. The ability to maintain postural control involves multiple neurologic pathways. Afferent information received from the body’s vestibular, visual, and somatosensory systems determine the corrective postural strategies employed to maintain balance. Proprioception is a precursor of good balance and adequate function. Proprioception has been defined as a specialized variation of the sensory modality of touch, which includes the sensation of joint movement (kinesthesia) and joint position (joint position sense). If proprioception is altered, a direct effect on balance can be expected.

Postural stability and kinesthetic awareness are important during athletic activities, such as running and cutting. These abilities may be adversely affected by musculoskeletal injury, delaying the rehabilitation progress and impeding sports performance.

Clinical assessment of static and dynamic balance may be performed using computerized instrumentation on the NeuroCom Balance Master System (Fig. 1) and the Biodex Balance System (Fig. 2), respectively. These machines provide a high degree of statistical validity and reliability in determining postural sway differences between limbs. They have been proven to have test-retest reliability of lower extremity functional instability measures involving testing situations of varying complexity.

These machines are not readily available in all treatment settings, so other reliable methods of testing have been used. The Star excursion balance test (SEBT) has been shown to be reliable and valid in determining postural deficits and is used to evaluate dynamic balance. During this test, the patient is required to stand on 1 leg while reaching in different directions with the other leg along diagonal lines marked on the ground. The distance that is attained in each direction is recorded and interpreted as representation of dynamic balance.

In an attempt to identify athletes with a greater risk for lower extremity injury, Plisky and colleagues examined the relationship between SEBT reach distance and lower extremity injury among high school basketball players. Results of the study revealed that a decreased normalized right composite reach distance and greater anterior right/left reach distance difference on the SEBT predicted lower extremity injury. This concept has several implications in terms of likelihood of injury for either limb. The first possibility is that the proficient limb might alter how the athlete reacts to competitive situations, causing increased stress to the more proficient limb. The second possibility is that the more adept extremity may absorb excessive force due to instability resulting from poor balance on the less adept extremity. The final possibility is
that the less adept lower extremity may not provide a stable platform on which to pivot or land.

This information allows rehabilitation clinicians and strength and conditioning specialists to be aware of weaknesses in players and the opportunity to take preemptive measures to avoid player injury.

**STRENGTH ASSESSMENT**

The assessment of lower extremity strength is a vital guideline in the safe progression of a patient throughout a rehabilitation program. Step-down tests have proven to be reliable and valid measurements to assess lower extremity strength.\(^{13-15}\)

**FORWARD STEP-DOWN TEST**

A modification of the Step Up-and-Over Test\(^9\) described by Neurocom, is the Forward step-down test.\(^{13}\) This test can be used earlier in the treatment paradigm to assess early single-leg function of the knee extensor muscle group.

The Forward Step-Down Test uses force plate technology to quantify the impact of descent during a forward step down from an 8-" step (Fig. 3) Measurements of the amount of vertical impact that occurs from the contact" of the contralateral limb are recorded. This measurement allows the clinician to determine the eccentric muscle strength of the limb that is performing the action of lowering the body to the ground. An increase in vertical impact scores demonstrates a loss of motor control coinciding with weakness in the knee extensor muscle group. A mean impact index of 10% body weight and a limb symmetry of 85% have been reported as normative values.\(^{13}\)

Additionally, the clinician should closely observe the quality of movement that the subject demonstrates. Qualitative assessment of the movement, including...
contralateral hip drop, ipsilateral hip hike, increased valgus of the knee, and increased plantar flexion (reaching) of the contralateral foot all demonstrate faulty movement patterns. These compensatory qualitative responses should be used to provide feedback to the athlete. If these responses are detected, advancement into another stage of rehabilitation can be discouraged until selective criteria for completion of the test are met.

The single-leg step-down test has also been proven to be useful in the identification of injury susceptibility. Earl and colleagues\textsuperscript{14} examined the differences in knee, hip, and ankle kinematics in patients using drop jump and single-leg step-down tests. The tests revealed that the drop jump produced greater knee abduction than the single-leg step down and is appropriate for evaluating anterior cruciate ligament (ACL) risk in athletes. The single-leg step down produced greater motion in the frontal and transverse planes at the ankle and hip and is appropriate for evaluating control of the hip. They concluded that both tests should be used together in the evaluation and examination of injury risk among athletes.

**ISOKINETICS**

Isokinetic dynamometry has been used since the 1960s to provide strength and power assessment of the elite athlete.\textsuperscript{16} Isokinetics has also been instrumental in providing

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**Fig. 2.** Dynamic balance testing using the Biodex balance master system (Biodex Corporation, Shirley, NY).
an effective tool in the assessment of the injured athlete returning to sport. Throughout the rehabilitative process, this type of testing proves to be useful in the functional progression model because of the quantitative, objective data it provides (Fig. 4). The objective data that are obtained provide a comprehensive assessment of muscle

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**Fig. 3.** Forward step-down test: The patient steps down an 8” step onto the force plate (Balance Master System) as slowly and as controlled as possible on each leg. Three trials are recorded. Mean impact and limb symmetry are calculated and interpreted. Lower extremity control is observed for deviations.

**Fig. 4.** Isokinetic knee testing on Biodex System 4 (Biodex Corporation, Shirley, NY).
torque, work, power, and acceleration. These measures, especially when comparing muscular strength of an injured extremity versus an uninjured extremity, provide pertinent information regarding the athlete’s response to rehabilitation.\textsuperscript{17} The nature of isokinetics provides a more controlled platform from which to test. This allows clinicians to test athletes with fewer degrees of freedom, allowing for a safer method to gain quantitative data on muscular strength and performance.

However, the validity of isokinetics in the assessment of athletic performance has been questioned in recent studies.\textsuperscript{18–22} Correlating the information obtained from this type of testing to athletic performance may be less useful due to the nature of the test. Typical isokinetics use isolated open-chain movements, which may be deemed less functional, especially when performed in a single plane of movement. On the contrary, athletic activities consist of closed-chain movements that are multi-plane and multi-joint in nature.\textsuperscript{23}

Therefore, isokinetics is a useful tool when assessing a patient progressing through a rehabilitation program. However, because the testing movement patterns involve joint isolation, the testing procedure is limited when attempting to assess the true sports performance of an athlete.

### HOP TESTS

The hop test was developed by Daniel and colleagues\textsuperscript{24} and was designed to gauge both strength and confidence in the involved leg. In contrast to isokinetic testing, the hop test is inexpensive to administer and uses movements of a more athletic-based nature. Various 1-legged tests for distance, 2-legged tests, and vertical jumps have also been established as measurements of the return to a functional level and the patient’s perception of knee function.\textsuperscript{25}

Measurement reliability has been reported for various hop-test procedures in non-impaired subjects, in impaired subjects who have undergone ACL reconstruction, and also in subjects with chronic ankle instability (CAI).\textsuperscript{26–30} An important reason for the continued use of the hop test in rehabilitation is its proven statistical validity. Several studies have reported intraclass correlation coefficient (ICCs) of high levels. In non-impaired individuals, ICCs averaged to be 0.94 for the single-hop test and ranged from 0.88 to 0.97 in subjects who underwent ACL reconstruction.\textsuperscript{26,28,29}

A combination of 4 different hop tests described by Noyes and colleagues\textsuperscript{31} may be particularly suitable as a clinical-based outcome measure for patients who undergo rehabilitation after ACL reconstructive surgery. The tests involve a variety of movement principles (including speed, direction change, rebound, and acceleration-deceleration) that imitate the demands of dynamic knee stability during athletic sports activities and are recommended for the patient to return to such activity.\textsuperscript{17,20,29,32,33}

This series of hop tests involves a single hop for distance, a 6-m timed hop, a triple hop for distance, and crossover hops for distance (Fig. 5). Measurements are obtained from both the operative and nonoperative extremities so that test performance on the impaired limb can be expressed as a percentage of test performance on the non-impaired limb, termed the “limb symmetry index” or LSI.\textsuperscript{32}

More recently, clinicians such as Augustsson and colleagues\textsuperscript{33} and Gustavsson and colleagues\textsuperscript{34} have stated that even the conditions under which patients perform hop tests can greatly influence the validity and outcome of performance. Augustsson and colleagues noted that although most sports injuries occur at the end of a sporting event, when the athlete is fatigued, patients are typically examined for return to sports using functional tests performed under non-fatigued conditions. They studied patients under both non-fatigued and fatigued conditions using a single-leg hop test for
distance. Their results showed that although no patients demonstrated abnormal hop test symmetry when non-fatigued 11 months post-operatively, two-thirds showed abnormal hop symmetry under fatigued test conditions. Furthermore, they found that patients are not fully rehabilitated 11 months after ACL construction. These findings have direct implications on clinicians’ use of the hop test and potential recommendations of return to sport.

Elaborating on the findings of Augustsson, Gustavsson and colleagues conducted a study to prove that a test battery evaluating different hop qualities (ie, maximum single-hop performance, as well as hop performance while developing fatigue) increases the opportunity to detect inconsistencies in hop performance (ie, increase the test sensitivity) compared with using only a single-hop test. After testing 5 different single-leg hop tests, they found that 3 of the 5 tests had a high ability to discriminate between the hop performance of the injured and the uninjured side both in patients 6 months after ACL reconstruction and in patients 11 months after an ACL injury. The 3 hop tests chosen for their test battery are the vertical jump, the hop for distance, and the side hop. Using these 3 tests, it was observed that among patients who had undergone ACL reconstructive surgery, 54% of patients obtained an abnormal LSI in all 3 tests and 91% obtained abnormal LSI values in at least 1 of the 3 tests. It was also found that the test battery produced higher values, in terms of test-retest reliability, sensitivity, and accuracy, than those with any of the 3 hop tests individually. This test battery may help in the process of deciding whether and when an athlete can return to strenuous physical activities after an ACL injury or reconstruction.

FUNCTIONAL MOVEMENT SCREEN

The concept of the FMS system was born from the realization that a significant number of athletes and individuals perform high-level activities with inefficient fundamental

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**Fig. 5.** Functional hop tests. A, Single-leg hop for distance; B, Triple hop for distance; C, Crossover triple hop for distance; D, One-legged timed hop.
movements. Individuals compensate for poor movement patterns by training around their pre-existing movement impairment or by not training their weakness during strength or conditioning programs. FMS identifies abnormalities in fundamental movements and allows a clinician to address them. When completed, the athlete or individual will have a better understanding of his or her own inefficient movements, which in turn will lead to improved performance, and ultimately decrease injury potential.

The FMS consists of 7 fundamental movement patterns that require a balance of mobility and stability. These movement patterns are designed to provide observable performance of basic locomotor, manipulative, and stabilizing movements. Placed in extreme positions, the tests reveal weaknesses and imbalances where stability and mobility are not appropriately used (Fig. 6). The 7 movement patterns are

- Deep squat
- Hurdle step
- In-line lunge
- Shoulder mobility
- Active straight leg raise
- Trunk stability push-up
- Rotary stability

The scoring of the FMS consists of 4 grades. Scores are simple in philosophy and range from 3, completion of the movement without any compensation to zero, wherein pain is present anywhere in the body during the movement. Five of the 7 movements test both the right and left sides, so it is important that both sides are scored. A difference in score between limbs indicates an imbalance and should be addressed with the conditioning plan or rehabilitation.

The most important aspect of the FMS in terms of athletic performance is its ability to preemptively identify and thus address physical impairments in athletes, minimizing or eliminating injuries. In an attempt to examine injury risk factors in professional football players, Kiesel and colleagues used the FMS to determine the relationship between the players’ scores and the likelihood of serious injury. The study revealed that if

Fig. 6. Functional movement screen: in-line lunge.
a player had an FMS score of 14 or less, his or her probability of suffering a serious injury increased from 15% to 51%. The findings of this study suggest the possibility that the application of FMS scores paired with preventive rehabilitation can help minimize the likelihood of sports-related injuries for all athletes.

VERTICAL JUMP TEST

To more fully understand recent advancements in the vertical jump test, the concept of isoinertial strength must first be discussed. In contrast to isometric, isokinetic, and isotonic assessments, isoinertial is more closely reflected in the underlying muscular effort throughout a weight lifting-type task. In other words, isoinertial loading implies a constant resistance to motion rather than merely a constant resistance or load throughout the lift. Murphy and colleagues observed that movements in athletic settings involve the acceleration and deceleration of a constant mass about the associated joints or articulations. Given this fact, it has been suggested that the assessment of isoinertial strength should be an important tool for diagnosis and for the designing of appropriate strength-training programs for athletes.

Advances in vertical jump testing have placed emphasis on digital technology and precision rather than on remedial vane/slat apparatus. More technologically advanced forms of the vertical jump test use force plates and timing mats, which provide precise and objective data in digital format.

In contrast to field hop tests (ie, the single-leg hop test for distance), the vertical jump force test (VJFT) addresses the measurement of force production. In a study conducted by Impellizzeri and colleagues, a VJFT was used consisting of the measurement of vertical countermovement during jumping with both legs. The purposes of the study included the examination of the correlation between the VJFT and other measures of lower extremity strength, including isokinetic knee extension and isometric leg press. The isometric leg press was measured by attaching a force plate onto a horizontal leg press and recording a subject's single-leg maximal isometric contraction.

The VJFT measurement was obtained by recording the vertical peak force produced by either the left or the right leg during a vertical jump. The results showed that there was only a moderate correlation between the VJFT and the isokinetic knee extension. This is explained by the fact that the isokinetic test isolates the knee joint, which is commonly observed with most open-chain movements. This suggests that the VJFT and the isokinetic knee-extension test are not interchangeable when assessing bilateral strength asymmetry. On the other hand, the isometric leg press test is more closed chain in nature and employs knee joint muscles as well as the muscles acting at the hip and ankle joints. This suggests that isokinetic testing should be used when assessing specific muscles around a single joint. Subsequently VJFT and other similarly designed closed-chain tests should be used to provide a comprehensive measure of strength to assess movements that more closely mimic functional activities of sport.

YO-YO TEST

Once an athlete or patient is able to participate in field tests after rehabilitation, the strength and conditioning specialist may want to test various aspects of performance. A simple form of tests are the 'yo-yo' tests, in which the physical capacity of the athlete is evaluated in a quick and efficient manner. The tests consist of running activities that are relevant to many sports.
Two markers are positioned on the ground 20 m apart and an audio CD is played. The participant runs like a yo-yo back and forth between the markers at specified speeds that are controlled by the CD. The speed is continuously and regularly increased, and when the individual can no longer maintain the speed, the test is terminated. The results of the test (Fig. 7) are determined by the distance covered during the test.1

Other forms of the yo-yo test exist to not exhaust the participant or for patients who are still in the rehabilitative stage of recovery. In these cases, a yo-yo test is administered that allows the participant to stop and rest after a given time period, and the change in heart rate is documented to evaluate cardiovascular condition.1

In total, there are 3 yo-yo tests. The yo-yo endurance test ranges in time from 5 to 15 minutes and is used to evaluate the ability of the participant to work continuously for an extended period of time. This test is applicable for individuals participating in endurance exercise such as distance running.1 The other 2 tests, namely, the yo-yo intermittent endurance test and the yo-yo intermittent recovery test, have participants performing intermittent exercise and measure an individual's ability to repeatedly perform intense exercise.1,41

The yo-yo intermittent endurance test (Yo-Yo IR level 1) ranges from 10 to 20 minutes and is composed of approximately 5- to 18-second intervals of running interspersed with regular 5-second periods of rest.1 This test evaluates a participant's ability to perform repeated intervals over a longer period of time, leading to a maximum level of activation of the aerobic system. This test is beneficial for the athlete who performs interval sports, such as tennis, soccer, and basketball.

The yo-yo intermittent recovery test level 2 (Yo-Yo IR 2) lasts 2 to 15 minutes and concentrates on the ability of the patient to recover after intense exercise with a substantial contribution from the anaerobic system.41 Between each exercise period (ranging from 5–15 seconds) there is a 10-second pause. This test is well suited for athletes participating in sports that require periods of intense exertion following short recovery periods. Performing in sports in which the ability to perform intensive exercise after short recovery periods is essential to a positive outcome in competition. Such sports include football, soccer, and ice hockey.

The relationships between the results of yo-yo tests and athletic performance have been examined only in a few studies.41–43 Krutstrup and colleagues43 conducted a study of elite female athletes. The results indicated a significant correlation between high-intensity running at the end of each game half and the yo-yo intermittent test. This signifies that the test appears to be a useful tool in the evaluation of match-related physical capacity of soccer players.

Fig. 7. Yo-yo intermittent test.
SUMMARY

Athletes continue to strive to maximize their physical and physiologic abilities to improve performance during competition. This dictates the need to assess their physical capacity to prepare them for return from an injury or to institute strength and conditioning programs. Rehabilitation clinicians and strength and conditioning specialists serve to provide specific assessments that identify qualitative and quantitative information pertinent for athletic performance enhancement. These assessments must demonstrate variability in movement patterns to effectively evaluate sports-specific functional movements during play. Improvements of these testing techniques are important due to the continually progressing nature of athletics. Increasing the number of valid tests during a clinical or performance evaluation will ultimately increase the specificity and utility of the results.

REFERENCES


