Linear and multi-directional speed testing (on-field and off-field) protocols in senior and elite female football

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Short title: Linear and multi-directional speed testing in female football

Abstract:
Female football has had a considerable rise in popularity with millions of fans following matches during the recent Women's World Cup. Despite this, the football scientific literature is still biased towards male footballers; therefore, this review aims to present the most recent literature and best practices for assessing linear and multi-directional speed and underpinning physical qualities, and to offer practical recommendations based on the most recent evidence and authors' expertise for practitioners working with female football players. This review categorizes tests as on-field and off-field, highlighting common protocols, their advantages, and the existing limitations. Among the most common on-field tests we found the change of direction speed, horizontal deceleration, linear sprinting, and curved sprinting; while the suggested off-field tests are multi-joint isometric, single-joint isometric, isokinetic dynamometry, Nordic hamstring and vertical jumps. These tests are valuable tools for assessing players' physical abilities, serving as a benchmark for tracking physical changes throughout the season, and aiding practitioners in individualizing and optimizing training protocols. This review highlights that strength (eccentric, isometric, concentric, and reactive) and rapid force production are crucial for generating braking and propulsive forces, which underpin linear and multidirectional motion. In conclusion, the evidence and practical suggestions reported in this review will improve the practitioners' knowledge of which tests and the consequent training protocols can be used in senior and elite female football players. But practitioners need to be aware about the scarcity of comprehensive studies on female soccer which hinders a complete understanding of the reliability of all assessment protocols used.

Key words: women, soccer, accelerations, decelerations, change of direction, sprint.

INTRODUCTION

In the last decades, female football in England has had a considerable rise in popularity with millions of fans following matches (125); this trend was highlighted during the recent 2023 FIFA Women's World Cup when it was estimated a record attendance in the host country of almost two million and approximately 2 billion TV views worldwide (75). Despite this positive trend in popularity, the football scientific literature is still biased towards male footballers (82,104); therefore, more research specifically evaluating female players is needed. This is particularly important because of the physiological, hormonal, and anthropometrical differences that exist between the two sexes (4,23,104), and the socio-economic inequities in female football, which can impact the training process and the performance optimization of the players.

Football players need to be physically capable of performing high-intensity (physical and technical) activities in conjunction with tactical demands throughout the duration of the match (22). Football is classified as a multidirectional intermittent sport, in which high-intensity activities alternate with periods of recovery (96,97). Although the aerobic metabolism is dominant, which has a key function in the resynthesis of phosphocreatine and for maintaining players' energy levels throughout the game (which can last more than 90 minutes) (83,86), the key high-intensity actions are primarily reliant on anaerobic metabolism (6,71). From a match analysis perspective, female football players cover a total distance ranging from approximately 9 km to 11.5 km, with high-speed running (HSR >19.8 $km \cdot h^{-1}$) distances ranging between 344 m to 867 m (4,38,39). Previous research reported that the match demands, in particular at the top tiers of football, are evolving rapidly, with a 21% increase in distance above 19 $km \cdot h^{-1}$ observed from the 2015 to the 2019 FIFA Women's World Cups (58). In addition, female football players need to perform a variety of high-intensity linear and multidirectional speed (MDS) actions, such as linear and curvilinear sprinting, changes of direction (COD), accelerations, and decelerations (109,117). Consequently, players need to have an appropriate aerobic capacity, but in particular, need to have developed other physical capacities such as strength, power, speed, and COD ability to compete at a high-level (107). Practitioners must appreciate the importance of these high-intensity MDS anaerobic activities for the performance of other key tactical and technical elements of football, for instance, defensive closing down (i.e., pressing which involves acceleration to deceleration), retaking possession for transition (i.e., a COD action), and offensive overlapping runs (i.e., curvilinear sprint) (98), which highlight the importance of anaerobic metabolism in female football (66). In addition, the MDS actions have also been identified as key movements associated with goal scoring and defending scenarios in the Women's Super League (90).

It is well known that strength and power are prerequisites for sport-specific actions (e.g., jump, sprint) (124) which are fundamentally underpinned by net impulse (i.e., external net force ×

time). Strength and power tests can be used to evaluate female players' performance, to help practitioners identify the most suitable training protocols, and serve as a reference point for longitudinal monitoring of physical changes during the season. The rationale behind testing and training these physical capacities is supported by previous research that has found greater relative strength to be a predeterminant for sprint, COD, and jumping performance (129). This is unsurprising based on the impulse momentum relationship, whereby large net impulses lead to greater changes in momentum, and thus strength and rapid force production capabilities are central for generating large braking and propulsive forces (76). Therefore, strength and conditioning coaches and sport scientists should test their players accordingly and subsequently tailor the training protocols on the basis of the needs of the players (4). However, to the author's knowledge, there is no clear picture regarding the research studies investigating linear and multi-directional speed testing and training protocols in female football. Research in female football has been recently highlighted by a narrative review (4), which called for more specific research involving female players, since the majority of the literature to date has focused on men's football (73,124). This represents a very practical issue as practitioners working with female players need to rely on evidence derived from the male literature (53), which is not always relevant or suitable. For such reasons, more information regarding testing and training specifically for female players is needed. This could help to improve the training of the players, improve the match performance, and reduce the likelihood of non-contact injuries.

Therefore, the aim of this narrative review is, firstly, to present the most recent literature and best practices for linear and MDS assessments and underpinning physical qualities, and secondly, to offer practical recommendations based on the existing evidence and authors' expertise for practitioners working with female football players. The evidence and practical suggestions reported in this review will improve the practitioners' (e.g., strength and conditioning coaches, sport scientists) knowledge of which tests and the consequent training protocols can be used in senior and elite female football players.

ON-FIELD TESTS

Change of direction speed testing

It is important to highlight that COD speed, maneuverability and agility are all separate and distinct qualities, but for the purposes of this section we are focusing on assessment of COD speed (76). When selecting a COD speed test, it is important to determine the most suitable protocol and measurement approach for female football players (4), and for the purpose of this review those specifically operating at the elite senior level. Currently, there is no recognized 'gold standard' protocol or measurement approach recommended for the assessment of COD speed in female football players (4). However, there is a general consensus that to effectively profile COD speed the test protocol should be of short duration, involve one turn, and provide information on what happens throughout the COD (i.e., COD strategy and movement quality) in addition to just COD completion times (102,115,130). For diagnostic purposes the latter is vitally important since the skill of COD involves distinct sub-phases including an initial acceleration, deceleration, turn and re-acceleration (depending on angle), with each of these sub-phases having unique physiological and biomechanical demands (44,45,67,130).

Sharp COD's (>60°) have a substantially greater braking demands than shallower COD angles (<60°) due to the necessity to decelerate momentum prior to turning (45,47) and are commonly associated with high lower-limb mechanical forces (45) and subsequent anterior cruciate ligament injury risk in elite female senior soccer players (85). Therefore, COD tests that employ sharp COD angles could be deemed particularly important to test, particularly for this population of players. The 505 COD speed test includes a sharp 180° turn, can be performed with different approach distances (i.e., 5m, 10m, 15m) and is commonly used to obtain more detailed insights on a player's COD performance, including phase specific COD information (102,115,130) and identification of asymmetries (i.e., directional dominance) that could identify deficiencies in both COD performance and factors that may place elite senior female soccer players at greater risk of injury (119,126). Importantly, the 505 COD speed test can also serve a dual purpose for assessing deceleration ability from a pre-determined distance (130), therefore essentially being a 'two-for-one' test. However, due to multidirectional requirements associated with female soccer, and the requirement to be equally proficient at turning both left and right across a spectrum of shallow, moderate, and sharp angles, and it could therefore be recommended to evaluate COD ability across a spectrum of angles to build a COD angle profile for female football players (e.g., 5 x 5m 60°; (37)), as recently adopted in basketballers (63).

For female senior soccer players operating at the elite level, it is important to obtain valid, reliable, and precise information on COD performance (11). The use of indirect measurement approaches to obtain more detailed information on the different sub-phases of 505 COD performance have included the use of timing gates to obtain 'deficits' in COD performance (i.e., COD and deceleration deficit) by comparing COD times to linear sprint times (28,102) and through using multiple timing gates to obtain split times in different phases of the 505

COD test (115). Whilst these approaches have helped to attain ‘proxy’ indicators of the desired outcome measurement (i.e., deceleration, COD) they do not provide continuous velocity measurements to enable phase-specific COD performance profiles to be obtained. Phase specific information regarding COD performance enables practitioners to identify “how” the overall completion time was achieved by dividing the COD time into different components such as initial acceleration, deceleration, and reacceleration (Figure 1). Technology such as motorized resistance devices, radar, laser, and LiDAR technology can facilitate these instantaneous velocity measurements. These technologies can be costly however, so an alternative approach during 180° tasks is to use high-speed cameras and divide the turn into approach, COD, and exit (see Jones et al., 2023 (77) for further information).

*****Add Figure 1 here, please*****

The use of video can also provide qualitative information on the ‘quality’ of the COD (e.g., joint kinematics) and has therefore been recommended to be included in conjunction with the quantitative outputs when profiling COD performance (43,102). For example, the cutting movement assessment score is a qualitative screening tool has been validated against 3D motion analysis for identifying athletes who display higher knee joint loads (i.e., ACL injury risk surrogate) during side-step cutting, and has been used successfully during pre-planned and unplanned tasks in female footballers (101). Based on current research and technological developments, performance staff working with elite senior female football players should endeavor to collect continuous COD velocity measurements alongside qualitative video footage to enable more precise individualized COD training prescription to be made (Table 1).

*****Add Table 1 here*****

Horizontal deceleration testing

Given the evidence linking horizontal deceleration and ACL injury (i.e., typically defensive pressing scenarios) in female football players (19,24,85), a strong case can be made for prioritizing the assessment of horizontal deceleration ability in this population. In addition to sharp COD tests (as explained in the previous section), horizontal deceleration can also be assessed using an acceleration-deceleration ability (ADA) test where a player either (a) sprints maximally across a pre-set distance before then decelerating maximally (68), or (b) sprints maximally and decelerates to a stop at a pre-set distance (Figure 2).

*****Add Figure 2 here*****

Similar to the measurement of COD performance, field-based technologies that facilitate continuous velocity measurements (as highlighted in the previous section) should be used to obtain reliable deceleration performance measures such as average and peak deceleration, distance and time-to-stop (68). Figure 3 illustrates an example velocity-time profile measured using a radar device (Stalker ATS II) from an ADA test with deceleration commencing at a pre-set distance of 20 m. The time point immediately following maximum velocity (V_{max}) is used to define the start of the deceleration phase with the end of the deceleration phase defined using the lowest velocity (V_{Low}). The deceleration phase can then be further sub-divided into early (DEC_{Early}) and late (DEC_{Late}) deceleration sub-phases by using the time point associated with 50% of maximum velocity (50% V_{max}). This subdivision can help practitioners assess their players' deceleration strategies, which can help tailor the deceleration training.

*****Add Figure 3 here*****

Video has also been used in conjunction with ADA tests to enable qualitative evaluation of movement quality and biomechanics associated with high knee joint loading and subsequent ACL injury risk (108,123). For example, use of a 2-D thigh angle to predict ground reaction forces (123) and a combined 2-D scoring system to identify players with high knee abduction moments (108). As such the use of an ADA test can provide valuable horizontal deceleration performance information, in addition to the identification of players who may be at heightened risk of injury using the qualitative evaluation of the movement quality. Despite the importance of deceleration ability for female football, to our best knowledge Zhang et al. is the only study to provide normative deceleration performance data in national level, semi-professional, and amateur French female footballers (133).

Linear sprinting

Linear advancing motion, and specifically sprinting, is the most common activity prior to goal scoring in elite female football (90). Consequently, linear sprinting ability is crucial for team success for both attacking and defensive purposes. During female match-play, most sprints occur over short distances, 76% and 95% being less than 5 and 10 m, respectively (38). However, on occasion, players are required to sprint over longer distances and consequently adequate preparation for such activities (i.e., peak demands) is necessary.

The gold standard method to assess linear sprinting ability is an automated system with pressure-sensitive starting blocks and high-resolution cameras (69). However, such systems are impractical in most applied settings due to their high cost and consequently more cost-effective solutions such as hand-held systems, radar guns, photocell systems and global navigation satellite systems (GNSS) are more commonplace in football (see Table 2) (4,41). Hand-held systems, (e.g., stopwatches) are simple to use but are inherently limited by the reaction time of the individual and are therefore not recommended. Photocell systems, or 'timing gates', measure the time taken for an individual to sprint over a set distance(s). The use of dual-beam systems (as opposed to single beam) is recommended as they minimize the likelihood of a false signal from an outstretched arm or leg, as opposed to the participant's torso (84). Photocell systems permit the assessment of average speed, but unlike radar guns and GNSS, they are not suitable for measuring peak speed or providing instantaneous speed profiles. Radar guns and GNSS can evaluate performance across the entirety of a sprint thus allowing the determination of peak speed and distance to reach peak speed. Although a radar gun's peak speed monitoring is extremely accurate due to their acquisition frequency (e.g., Stalker ATS 2 = 34.7 GHz), its use during daily football activities is not as practical as the monitoring of physical data with GNSS, which is, nowadays, the most used technology for the monitoring of speed-related data. In recent years, peak speed data recorded using 10 Hz GNSS technology has been compared to the one recorded using radar gun (r = 0.98, nearly perfect, error ~2%) demonstrating that GNSS is a valid alternative (3), as well as other research demonstrated that peak speed data are reliable (inter-units) during linear sprint activities (from 5 to 30 m) (5) intermittent short shuttle runs (9). One of the main advantages of GNSS is that it permits "invisible monitoring", simultaneous testing of multiple athletes, and the evaluation of peak speed during training and matches. Logistically GNSS presents a great advantage, specifically, the practitioners can test multiple athletes simultaneously.

The distance utilized during linear speed testing is determined by the variable of interest, for example, short distances (< 20 m) are used when considering acceleration, whereas longer distances (> 30-40 m) are used to when considering peak speed (4). As with any testing protocol, it is important to give due consideration to the standardization of the testing protocol. Consequently, the practitioner must consider whether to utilize a fixed or 'flying' start position. If a fixed position is elected, there are various options including standing sprint start, three-point, and block sprint start. Familiarization prior to testing is crucial, particularly for start positions which may be considered more technical (as three-point and block, although the authors do not recommend these stances because they are not sport-specific) (50). Flying starts are often used if the criterion measure is peak speed. It is common practice for the player to stand a set distance behind the start line to avoid breaking the beam prior to the sprint, with distances customarily ranging from 0.3 – 1.0 m. Additionally, the practitioners who want to analyze the acceleration/sprinting technique and upright sprinting mechanics, have the opportunity to do so using 2D analysis systems (e.g., smartphone) and an in-field assessment tool (18,74,88,116,132). The authors highlight the role of technique and movement proficiency in the improvement of speed for both linear and multi-directional movements. Finally, the priority for practitioners is to ensure test reliability and therefore standardization of start position and start distance are crucial to permit player comparisons and for evaluating player performance longitudinally. For instance, practitioners should standardize testing surface and environmental conditions; since these topics are outside the scope of this review, we encourage the readers to look at these articles (4,27,99,132).

*****Add here Table 2, please*****

Curved sprinting

Most sprints in football are not purely linear, but curved, defined as the upright running portion of the sprint completed with the presence of some degree of curvature (62). Given the prevalence of sprinting maneuvers executed along curvilinear paths, a specialized sprint test for football players was previously developed (62). This assessment leverages the curvature of the penalty area on a standard football field, encompassing 17 meters (62). The reliability of this curvilinear sprint test was verified in male players, boasting an intra-class correlation coefficient ranging from 0.75 to 0.96, with a coefficient of variation spanning from 0.5 to 1.97% (62). Regarding the interrelation between the curvilinear sprint test and the traditional linear 17-meter sprint evaluation, the findings indicate a limited connection, as the coefficient of determination ranges between 0.34 and 0.37 (62). These outcomes imply that the skills required for curvilinear and straight-line sprinting exhibit a certain degree of independence from one another. Consequently, this substantiates the inclusion of both linear and curvilinear sprinting exercises within the assessment batteries of football players (see Table 2).

Interestingly, the relationships between straight sprinting and curve sprinting appear to be age dependent. A previous study comparing football male players under the ages of 15, 17, and 20 (59), who performed both straight and curved sprints, underscored the importance of evaluating and training curved sprinting across different age groups, revealing that the relationships become less correlated with linear sprinting as age increases. Additionally, the same study revealed that curve asymmetry was significantly higher among players aged 20 and above compared to those under 15 and 17 (59). The study suggests that to mitigate the rise in asymmetries resulting from the specialization process, focusing interventions primarily on improving the weaker side during curved sprints. The utilization of the curved sprint test presents a unique opportunity to assess the impact and performance of executing curves towards a specific direction. Research by Filter et al. (61) examined nine adult football players, contrasting the performance of the inside versus outside leg during curved sprints. Their findings indicated that the inside leg exhibited a longer foot contact time along the curvilinear trajectory, compared to the outside leg (61). Moreover, significant variations in foot contact time were observed between the "weak" and "good" sides, determined by the worst and best successful attempts, respectively.

In comparing straight sprints to curved sprints (61), electromyography analysis revealed no discernible differences between legs in terms of root-mean-square peak percentage, when normalizing mean values from the five highest peaks observed in each task during straight sprints. However, during curved sprints, activation of hip external rotation muscles (such as biceps femoris and gluteus medius) increased during outside leg side-stepping, as a response to counter applied valgus and hip internal rotation moments at the knee (61). Conversely, during inside leg cross-stepping cuts, activation of hip internal rotation muscles (semitendinosus and adductor) increased compared to outside leg sidestepping cuts, serving to counter applied varus and hip external rotation moments at the knee (61). These findings underscore the distinct roles played by each leg during curve sprinting, shedding further light on the biomechanical intricacies of the movement (61). They also suggest that the inside leg may play a crucial role in limiting the maximum running speed during curvilinear sprints. This difference between legs can serve as a focal point for introducing new variables, such as curve sprint asymmetry (60). This approach may enable the detection of players' degrees and directions of inter-limb asymmetry, ultimately aiding in the identification of each football player's dominant curve side (60). Such insights could significantly enhance the characterization and profiling of playing positions in the sport.

OFF-FIELD TESTING

A range of different muscle strength qualities are associated with faster sprint and COD performance and are needed when executing these actions (1). For example, using a common COD test identified earlier – the 505 test, Table 1 provides a technical framework for a 180° turn performed within the test, which identifies several required muscle-strength qualities and potential assessments. Note the approach and re-acceleration phases highlight important muscle strength qualities for maximum velocity and acceleration sprinting, respectively. Combining these assessments would help practitioners with providing a more holistic profile of a female player to better individualize the players MDS development. Table 1 highlights that eccentric, isometric, reactive, and concentric strength, RFD, and impulse are required across the preparation (penultimate foot contact), execution (e.g., 'plant' incorporating braking, transition [max knee flexion] and propulsion sub-phases, thus eccentric-concentric coupling), and re-acceleration phases of COD actions. Ground contact times of 180° turns are typically >400 ms (78,80,81,120), thus, may place greater emphasis on slow SSC function. However, it should be noted that ground contact times are influenced by the approach and angle of direction change (45), with COD angles ≤45° typically ≤250 ms (70,121,128). Hence, assessing and developing female players slow and fast SSC function is important to cater for the COD demands in female football. Additionally, because of the time constraints associated with the 'plant' phase of changing direction and the steps preceding and following this, the ability to produce rapid and high magnitudes of net force (i.e., rate of force development and impulse) to decelerate and accelerate the mass, redirecting the COM is fundamental (45). The remainder of this section is divided into the potential tests of physical qualities identified including multi- and single- joint isometric testing, vertical jumps (assessment of SSC function) and tests of eccentric strength (see table 1).

Multi-joint isometric testing

Due to the importance of the lower-limb triple extensor joints (hip, knee, and ankle) and musculature for braking and propulsion during MDS actions (91), multi-joint lower limb assessments, such as the isometric mid-thigh pull (IMTP, see Table 3) (4,56), isometric squat test (49), unilateral isometric squat (15), are valuable assessments for monitoring the maximal and rapid force production characteristics in female footballers. Although various aspects of technology are available to assess isometric strength qualities of athletes (i.e., crane scale, load cells, dynamometers), the following section will focus on force platform technology due to their portability, accessibility, and ability to provide rich force-time data for insights into neuromuscular function (29). Specifically, the IMTP assessment is a safe, time-efficient, less fatiguing, and surrogate measure to traditional 1RM testing (29). But, importantly, in addition to providing insights into maximal force production, time-limited force expression (i.e., impulse, RFD, and time-specific force) during contact times of MDS actions (i.e., 100, 200, and 300 ms) can also be examined which are key determinants of MDS performance (i.e., impulse). A range of different data collection and analysis procedures can be adopted for IMTP assessments which can affect resultant values and the subsequent validity and reliability (29). As such readers are encouraged to read the methodological recommendations by Comfort et al. (29) and thus, a brief overview is provided.

*****Add Table 3 here*****

The IMTP is traditionally performed in an isometric rig where bilateral force production is commonly assessed. If practitioners have access to dual force platforms, bilateral asymmetries can be monitored; however, the task can also be performed unilaterally which may provide greater specificity to MDS actions and can provide insights into inter-limb asymmetries and "windows for further development" (46). For specific details about the position and posture of the athletes, read the following paper (29). Once posture is established and two to three warm-up trials are completed, practitioners should instruct the participant to remove slack from the bar and system, while trying to minimize excessive pre-tension. A stable weighing period is essential for determining body (system) weight, subsequent initiation (i.e., 0 ms start) and athletes should be cued to "pull the bar and push their feet directly downwards into the force platform(s) as fast and as hard as possible" for 3-5 seconds to produce optimal results (29). If interested in time-limited force expression, 1 second rapid efforts could elicit greater values (65). Two to three trials are advocated with ~ 1 min rest between trials with differences in peak force <5% (29). Trials with a clear countermovement and substantial changes in joint angles should be discarded and reperformed (29).

Commercially available software can analyze IMTP force-time data using proprietary algorithms; however, key force-time metrics can be calculated manually using Microsoft Excel (or alternative software). An analysis spreadsheet is openly available by Chavda et al. (25). A plethora of force-time metrics are available for subsequent evaluation, however, the following metrics are recommended (25): net relative peak force for insight into maximal force production and net relative force (i.e., at 50, 100, 150, 200, 250, and 300 ms) for insights into rapid force production characteristics. Intuitively changes in net time-specific force would be reflected with changes in RFD and impulse. Additionally, practitioners should be cognizant of body weight (Newtons) and initiation threshold when longitudinally monitoring changes in neuromuscular performance. Furthermore, practitioners may consider normalizing time-specific force values relative to peak force to establish how much of an athlete's maximum force production capacity is being utilized to inform training priorities (i.e., maximal or ballistic training) (29). To our best knowledge, currently, normative data pertaining to IMTP is limited to elite female youth football players (u10s-u16s) (54,55), showing the metrics to be reliable, with age and maturity status impacting peak force and impulse. Further data is required in senior elite female football players and thus, a future direction of research (4). Finally, practitioners may decide to use an isometric squat assessment which has been shown to elicit greater force and impulse values compared to the IMTP (17); however, the associated spinal compression and discomfort with the isometric squat may influence compliance.

Single joint isometric hip tests

The popularity of single joint isometric hip tests using force platforms has increased dramatically in recent years. Partly due to the increased availability of commercial force platforms and associated proprietary software enabling immediate feedback, but also due to the remaining high incidence of hamstring strain injuries (HSI) in many multidirectional sports (21). Furthermore, hip extensor strength is important to resist increased hip flexor moments (78,81); during penultimate and final foot contacts of COD and crucial for linear sprint acceleration. Table 1 highlights that eccentric strength of the hamstrings is important to control the deceleration of the lower limb during the late/terminal swing phases in preparation for ground contact during sprint running. It is this phase which is often implicated in the aetiology of HSI (26,118) and thus, eccentric hamstring weakness here is considered a risk factor for HSI. One of the drawbacks of eccentric hamstring testing is the fatigue and subsequent muscle soreness (although previous familiarization with eccentric exercises should limit the onset of muscle soreness) associated with the eccentric exercise (113) and thus, isometric hamstring tests are viewed as less fatiguing and muscle damaging alternatives to monitor changes in hamstring strength following games or during the season.

There are various iterations of the isometric hamstring test, but two main ones are the supine hamstring 90/90 (90° knee and hip flexion) and 30/30 (30° knee and hip flexion) (32,92). These tests have been shown to have good between-session reliability and sensitive enough to detect reductions in force following a competitive football match in professional male players [n=29] (92) and professional youth male players (32). Thus, the tests may enable regular evaluations to determine match-induced fatigue and monitor recovery to help inform decision-making regarding modifications to individual players training load. Cuthbert et al., (36) conducted on female football players (n=29) competing in the English women's super league, have reported acceptable within and between session absolute reliability [CV ranging from 4.85% (Isometric 30/30 right within session) to 10.23% (isometric 90/90 left between session)] and poor to good [ICC ranging from 0.698 (isometric 90/90 left between session) to 0.881 (isometric 30/30 right within session)] relative reliability. Further research again on female football players competing in the English women's super league (113), reported excellent absolute and good relative between session reliability for peak force (CV = 2.84%, ICC = 0.898), and good to excellent absolute and poor to moderate relative reliability for rapid force generating measures (CV% <8.33%, ICC >0.610). These values are similar to values (CV = 4.34-5.38%; ICC = 0.95) reported by McCall et al. (92) and would suggest that such tests could be used by female players to monitor changes in hamstring strength in relation to training and match loads.

It is recommended that minimum operating standards are developed to ensure reliable data collection such as not wearing shoes for the test to avoid the rubber sole dampening a force response and ensuring the hips are fixed so that knee and hip angles are standardized and maintained throughout the test (113). Furthermore, to obtain measures of rapid force production a sampling rate of 1000 Hz maybe required, and a reliable and accurate onset threshold should be used (113). These authors used 5 × SD of residual force like that recommended for IMTP testing (42). For normative data on female soccer players the reader is directed to the following research (36,113). Finally, practitioners may be interested in assessing other muscle groups and joints such as the soleus/ankle plantar flexors (ankle extensors) using force platforms due to the relevance of ankle joint power to change of direction maneuvers such as side-step cutting (89). The interested reader could refer to work by Rhodes et al., (2022) (112) on male football players; however, the authors are unaware of research conducted on female football players in this regard.

Assessment of eccentric lower limb strength

Table 1 highlights the importance of eccentric knee and hip extensor and knee flexor strength during the penultimate and final 'plant' foot contacts during a 180° COD to absorb the large knee and hip flexor moments experienced during braking. Indeed, research on female football players has highlighted the importance of eccentric strength during various COD maneuvers (4,78). Jones et al., (78) observed large correlations between a 180° COD task completion time and isokinetic (60°/s) eccentric knee extensor ($R = -0.674$) and flexor ($R = -0.603$) strength and moderate to large correlations between approach velocity and COD time ($R = -0.484$) and eccentric knee extensor strength ($R = 0.724$). Furthermore, stronger participants ($n = 9$) recorded significantly ($p < 0.05$) faster approach velocity ($d = 1.27$) and a greater reduction in velocity ($d = 0.94$) during penultimate foot contact than weaker ($n = 9$) subjects. In another study examining 60-90° side-step cutting in female soccer players (79), eccentric knee extensor strength was significantly ($p < 0.05$) largely associated ($R \geq 0.610$) with velocities at key instances during the task and when divided into eccentrically stronger and weaker players, stronger players ($n = 9$) achieved higher velocities ($d = 1.34$-1.71) throughout the maneuver than weaker players ($n=9$) who showed slightly greater deceleration ($d = 0.36$-0.38) during penultimate and final foot contacts. Furthermore, stronger players achieved significantly shorter penultimate and final ground contact time, with significantly (moderate) greater average horizontal braking forces. Collectively, these studies highlight the importance of eccentric strength during COD maneuvers; in tasks whereby, initial momentum is required to be reduced to zero before accelerating again (e.g., 180° COD), players with greater eccentric strength approach faster (i.e., self-regulation) as they can handle the greater braking forces experienced and make better use of the penultimate foot contact to decelerate. Whereas COD tasks involving shallower directional changes (e.g., 60-90°) the maintenance of velocity is more important, thus, eccentrically stronger players approach faster and are better able to maintain velocity throughout the maneuver as they are better able to handle the greater GRFs experienced maintaining shorter ground contact times to avoid large reductions in velocity (e.g., avoid elevating braking impulse creating reductions in velocity).

Isokinetic dynamometry

Isokinetic dynamometry maybe considered the 'gold standard' method of assessing eccentric strength of the knee extensors and flexors and several studies have reported isokinetic data in female football players of various ages and levels (12,34,72). However, only a few have reported eccentric knee extensor or flexor peak moments of female soccer players (57,87). These studies could act as normative data, however, differences in soccer population, devices used, angular velocities and modes used in the protocol, definition of limbs used (e.g., limb dominance) and the reported variables make it difficult to draw comparisons between studies. Whilst isokinetic dynamometers can derive several parameters (see Table 3), strength during isokinetic assessment should be quantified by the maximum moment and should be achieved within 3 to 6 repetitions (12,34,72). An average moment (peak) from several trials should not be reported, as this may be taken from different joint positions and therefore, does not provide information about the joint-moment position relationship (12,34,72). Practitioners need to decide on an appropriate angular velocity at which to assess the players and it may be suggested that $60°\cdot s^{-1}$ is more common on studies involving female and male soccer players (10,12,106). Many practitioners may consider assessing at faster speeds $>180°\cdot s^{-1}$, to provide an assessment at more 'functional' sports specific speeds (33). However, measurement limits of many dynamometers will not be able to replicate the angular velocities of many multidirectional speed actions which commonly exceed 300°/s (110). Furthermore, measurement at greater angular velocities reduces the available 'isokinetic range' as greater ranges of movement are required to accelerate to and decelerate from faster velocities, reducing the reliability of isokinetic parameters at faster isokinetic velocities (72,110).

Nordic hamstring exercise and NordBoard

The use of isokinetic dynamometers is considered by many to lack 'functionality' due to the seated position typically used when assessing knee extensor and flexor strength (64). Furthermore, the cost and availability of isokinetic dynamometers to practitioners as well as the time-consuming nature of the assessments reduces the potential utility of isokinetic dynamometers in applied practice (4,124). This has led to the emergence of other methods of eccentric strength assessment that can be more easily administered in training environments.

The NordBoard is a device based on the Nordic hamstring exercise (NHE) which has been widely used in hamstring injury mitigation programs to develop eccentric hamstring strength, hence, the potential for its utility in training environments, see Table 3 (8,21,52). During the exercise an athlete begins in a kneeling position with support around the ankles, slowly falls forward maintaining an anatomical neutral hip angle and attempting to resist the increasing gravitational moment by activation of the hamstrings (14). Once the athlete reaches a point where they can no longer resist the increasing gravitational moment, they reduce effort and fall to the floor making contact in a press-up position. A NordBoard device measures the forces acting through both limbs where the athlete is supported around the ankles through strain gauges. Opar et al. (105) have reported the NordBoard to be highly reliable (ICC = 0.83 – 0.90; CV = 5.8-8.5%) and able to detect residual weakness in previously injured elite athletes (105,127).

Prospective studies in male Australian rules football (105) and male football (Timmins et al., (127) found that low absolute NordBoard values (Australian rules <256N at the start of pre-season and <279N at the end of pre-season; football <337 N) increased the chance of hamstrings injuries. Contrary, Bourne et al. (16) found no association between low eccentric strength assessed through the NordBoard and hamstring injuries in male rugby union players of various levels during one season but did find large bilateral imbalances to be associated with hamstrings injuries. Similarly, Roe et al. (114) found no association between NHE forces and hamstrings injuries in elite male Gaelic football players tracked over 12 weeks and van Dyk et al.(51) found no association of NHE force and many other isokinetic parameters to hamstring injuries in professional male football players in one Qatar national league season, highlighting the multifaceted nature of hamstrings injuries. Limited data is available on female football players, however, Cuthbert et al. (36) reported fair to excellent reliability within-session (ICC ≥ 0.784, lower bound 95% CI ≥ 0.623) and good to excellent between-session reliability (ICC ≥ 0.91, lower bound 95% CI ≥ 0.790) of NHE forces in 29 female football players. The authors also reported acceptable variability both within- (CV = <4.88% left; <4.86% right) and between-session (CV = 2.89% left; 4.01% right) and substantial agreement (k= 0.62) in identifying inter-limb asymmetry between sessions, suggesting the NHE as an appropriate method to monitor inter-limb asymmetry over time in female football players (36).

Whilst the NordBoard has good practical utility it is not without limitations. Theoretically the resistive moment achieved by the two limbs combined (e.g., force attained from the strain gauge × the distance from the strain gauge to the knee joint axis for both limbs) achieved during the NHE at the point of breakpoint (when the player can no longer resist the gravitational moment and falls to the ground) is equal to the gravitational moment of the head, trunk, upper limbs and thighs about the knee joint at that point. The gravitational moment will of course depend on the height (in particular length from knee to head) and mass of the player which could influence the forces achieved during the NHE. Indeed, Buchheit et al. (20) found a large (R=0.55) association between NordBoard eccentric knee flexor strength and body mass in 81 football players of differing ages and playing ability and 41 Australian football players. This highlights that NHE forces are body mass dependent and thus, values must be normalized by body mass to allow meaningful comparisons between age groups and with normative data. Eccentric knee flexor strength determined during the NHE has relatively low association (R <0.58; R2 <34%) and agreement to eccentric peak moments attained from isokinetic dynamometry (131). This is because often the range achieved by individuals during a NHE does not cover the angle of peak moment for the hamstrings, which is closer to full knee extension. Therefore, the NordBoard and isokinetic dynamometry are assessing different aspects of eccentric muscle action, and the NordBoard cannot consistently evaluate peak eccentric moment or force of the hamstrings unlike isokinetics. Furthermore, unlike isokinetics the speed of descent of the NHE cannot be controlled without additional measures (e.g., video tracking of center of mass velocity), which may further influence the tension developed in the hamstrings and thus, the force output from the strain gauges of the NordBoard.

Vertical jumps: assessment of SSC function

MDS actions such as sprinting and COD involve rapid triple extension of the hip, knee, and ankle and eccentric-concentric coupling mechanism) (91). As such, vertical jumps from static positions such as the squat and CMJ, and rebound jumps (e.g. drop jumps, 10/5 repeated jump test) are valuable assessments which can provide unique insights into the impulsive, explosive, and reactive strength characteristics of athletes which underpin MDS performance (see Table 3). Specifically, the squat jump is performed from a static position (typically 90° knee flexion), with minimal involvement of the SSC, and is thus considered an indicator of rapid concentric strength and ballistic qualities (4,103). Conversely, the vertical CMJ, initiated from an upright position, does involve the SSC and represents "slow" SSC function (i.e., >0.25 s) due to time-to-take-off (TTT) durations generally lasting ~0.6 s (93) and providing insights into slow reactive strength and elastic equalities. Moreover, single rebound jumps tasks typically performed from boxes (i.e., 30 cm) and RJTs (i.e., 10/5 repeated jump test) evaluate “fast” SSC function with typical contact times < 0.250s (subject to athlete physical capacity) (35). Rebound jump tasks are typically performed with smaller lower-limb flexion angular displacements, in contrast to squat and countermovement jumps, and thus may share greater mechanical similarities (i.e., dynamic correspondence and coordinative overload) with upright sprinting and MDS actions, though the larger angular displacement could be more representative of initial acceleration (100).

A variety of different technologies are available to evaluate vertical jump height (and ground contact time where applicable) such as contact mats, camera technologies, optoelectronic, accelerometers, jump-and reach devices, and linear position transducers (30); however, despite their portability and ease of use, they generally calculate jump height based on flight time which is sensitive to errors (i.e., overestimations) due to alterations in body configuration at landing and take-off (30). Additionally, these technologies provide limited information regarding “jump strategy” and “how” the jump was performed. As such, as suggested earlier for isometric testing, force platform technology is recommended for vertical jump testing for deeper insight into phase-specific information and “how” the jump was achieved (i.e., "strategy" metrics) (95), which can have important implications for monitoring, talent identification, training readiness, and return to play (7,13).

Commercially available hardware and software using proprietary algorithms can calculate a range of different kinetic and kinematic measures (across different phases of the task) pertaining to potential neuromuscular function during vertical jump tasks (2). However, these force-time metrics can be calculated manually through processes of differentiation, integration, and forward dynamics, or openly available spreadsheets for the CMJ and drop jump (25,112). For the CMJ, while jump height is a key outcome metric, additional metrics such as time to take-off provides insights into movement strategy and can be used to calculate reactive strength index modified (jump height/time to take-off) whereby achieving a high jump height in a short time to take-off is a primary objective and indicative of superior reactive strength (13). Additionally, countermovement depth, and components of braking and propulsive impulsive (i.e., phase times and average forces) can also provide valuable insights regarding jump strategy (95), with a similar jump height performed with a shallower countermovement depth strategy considered superior (without negatively compromising net propulsive force). Finally, to account for body composition and body mass differences which could be present between players and positions, jump momentum is a suitable metric which may provide a fairer representation and comparison between athletes regarding the ballistic and reactive strength qualities. Reference data pertaining to CMJs in English national youth and senior football players on a contact mat was reported by Datson et al (40). To our best knowledge, however, no data exists in elite female football players related to CMJ force-time data and is thus an area of future direction of research.

Traditional rebound jump testing involves dropping from a height and upon contact with the ground, rebounding for maximal height in a short ground contact time (31). Conversely, a repeated jump test is usually initiated with a countermovement and several consecutive repeated rebound jumps are then performed (122). Indeed, jump height, contact time, and subsequently reactive strength index (jump height/contact time) are considered key outcome metrics related to fast SSC and neuromuscular function (i.e., maximize jump height and shorten contact time) which can be collected without force platform technology. However, during drop jump testing, researchers have shown that actual fall height from a box may not correspond to the box height (i.e., athlete raises or lower center of mass) which therefore does not result in a homogeneous fall height within- and between individuals (94). With the use of force platforms, measuring body weight after the jump-landing, the actual fall height can be calculated using the equations provided by McMahon et al. (94) and should be monitored when inferring reactive strength qualities in athletes. In addition to the previously mentioned metrics, Pedley et al. (111) using force platforms, advocates analyzing additional metrics including, spring like-behavior (utilizing vertical displacement and vertical force data), vertical stiffness, impact peak and timing of peak braking, for insights unto SSC function. Spring-like behavior, short CTs, high JHs, high vertical stiffness, without early impact peaks is desired and theoretically represents a mechanical ability to effectively utilize potential elastic energy. International level female soccer reactive strength index values during the 10/5 repeated jump test are provided by Doyle et al. (48) but to our best knowledge, fast SSC function data in line with Pedley et al. has yet to be provided (111).

Limitations and future directions

The testing protocols outlined present evidence-based practices that might allow practitioners to take advantage of theoretical and technological advances that have occurred over the past decade in sport science. Each of the tests recommended can facilitate the development of individualized training programs and enhance the physical profile of women's football players. However, this review is not without limitations, first, it is not a systematic review of the existing literature. Although the authors have summarized the current evidence to the best of their knowledge, it is not possible to state that all existing studies have been reported. Due to the nature of this review, some specific and rigorous aspects of a systematic review have not been used, specifically, search terms, databases used, and inclusion and exclusion criteria. Secondly, to date most of the research has focused on male soccer players. Previous literature has highlighted the challenges and limitations of translating results from male to female players; therefore, further research is needed to better understand the biomechanical and physical profiles of female soccer players. Furthermore, given the limited existing literature on female soccer, it is not possible to fully understand the test reliability (i.e., CV and ICC) of all used assessment protocols. Reliability (e.g., test-retest) plays a paramount role for the selection of the test protocols, as well as help to accurately create target scores for players; therefore, there is a need for further research in this area that includes female players to determine the test-retest reliability and the development of normative values for female players. Such research will be beneficial for practitioners working with female players when choosing their testing battery and to inform athletic development strategies for female players.

Conclusions

This narrative review presented the most recent literature and best assessments practices for linear and MDS tests as well as offered practical recommendations for practitioners working with female football players. This review categorized tests as on-field and off-field highlighting some of the most common protocols, their advantages, and the existing limitations. These tests are valuable tools for assessing players' performance, aiding practitioners in individualizing and optimizing training protocols, and serving as a benchmark for tracking physical changes throughout the season. The importance of testing and training these physical capacities is supported by prior research, which identified greater relative strength as a key determinant for sprint, COD, and jumping performance. It is clear that strength (eccentric, isometric, concentric, and reactive) and rapid force production capabilities are crucial for generating significant braking and propulsive forces, which are needed to perform linear and multidirectional actions. In conclusion, the evidence and practical suggestions reported in this review will improve the practitioners' knowledge of which tests and the consequent training protocols can be used in senior and elite female football players. However, practitioners need to be aware about the scarcity of comprehensive studies on female soccer which hinders a complete understanding of the reliability of all assessment protocols used. Therefore, more research involving female players is needed to ascertain this reliability and to establish performance standard values.

References

1. Asimakidis, ND, Bishop, CJ, Beato, M, Mukandi, IN, Kelly, AL, Weldon, A, et al. A survey into the current fitness testing practices of elite male soccer practitioners: from assessment to communicating results. *Front Physiol* 15, 2024.Available from: https://www.frontiersin.org/articles/10.3389/fphys.2024.1376047/full
2. Badby, AJ, Mundy, PD, Comfort, P, Lake, JP, and McMahon, JJ. The validity of hawkin dynamics wireless dual force plates for measuring countermovement jump and drop jump variables. *Sensors* 23: 4820, 2023.Available from: https://www.mdpi.com/1424-8220/23/10/4820
3. Beato, M, Coratella, G, Stiff, A, and Dello Iacono, A. The validity and between-unit variability of GNSS units (STATSports Apex 10 and 18 Hz) for measuring distance and peak speed in team sports. *Front Physiol* 9: 1288, 2018.Available from: https://www.frontiersin.org/articles/10.3389/fphys.2018.01288/abstract
4. Beato, M, Datson, N, Anderson, L, Brownlee, T, Coates, A, and Hulton, A. Rationale and practical recommendations for testing protocols in female soccer: a Narrative Review. *J Strength Cond Res* , 2023.
5. Beato, M and De Keijzer, KL. The inter-unit and inter-model reliability of GNSS STATSports Apex and Viper units in measuring peak speed over 5, 10, 15, 20 and 30 meters. *Biol Sport* 36: 317–321, 2019.
6. Beato, M, de Keijzer, KL, and Costin, AJ. External and internal training load comparison between sided-game drills in professional soccer. *Front Sport Act Living* 5: 1–10, 2023.Available from: https://www.frontiersin.org/articles/10.3389/fspor.2023.1150461/full
7. Beato, M, Madsen, EE, Clubb, J, Emmonds, S, and Krustrup, P. Monitoring readiness to train and perform in female football: current evidence and recommendations for practitioners. *Int J Sports Physiol Perform* 19: 223–231, 2024.Available from: https://journals.humankinetics.com/view/journals/ijspp/19/3/article-p223.xml
8. Beato, M, Maroto-Izquierdo, S, Turner, AN, and Bishop, C. Implementing strength training strategies for injury prevention in soccer: Scientific rationale and

methodological recommendations. *Int J Sports Physiol Perform* 1–6, 2021.Available from: https://journals.humankinetics.com/view/journals/ijspp/aop/article-10.1123-ijspp.2020-0862/article-10.1123-ijspp.2020-0862.xml

9. Beato, M, Wren, C, and De Keijzer, KL. The inter-unit reliability of global navigation satellite systems Apex (STATSports) metrics during a standardized intermittent running activity. *J Strength Cond Res* Ahead of p, 2023.

10. Beato, M, Young, D, Stiff, A, and Coratella, G. Lower-limb muscle strength, anterior-posterior and inter-limb asymmetry in professional, elite academy and amateur soccer players. *J Hum Kinet* 77: 135–146, 2021.Available from: https://www.sciendo.com/article/10.2478/hukin-2020-0058

11. Bernards, J, Sato, K, Haff, G, and Bazyler, C. Current research and statistical practices in sport science and a need for change. *Sports* 5: 87, 2017.Available from: http://www.mdpi.com/2075-4663/5/4/87

12. Bishop, C, Coratella, G, and Beato, M. Intra- and Inter-limb Strength asymmetry in soccer: a comparison of professional and under-18 players. *Sports* 9: 129, 2021.Available from: https://www.mdpi.com/2075-4663/9/9/129

13. Bishop, C, Jordan, M, Torres-Ronda, L, Loturco, I, Harry, J, Virgile, A, et al. Selecting metrics that matter: Comparing the use of the countermovement jump for performance profiling, neuromuscular fatigue monitoring, and injury rehabilitation testing. *Strength Cond J* Publish Ah, 2023.Available from: https://journals.lww.com/10.1519/SSC.0000000000000772

14. Bishop, C, Manuel, J, Drury, B, Beato, M, and Turner, A. Assessing eccentric hamstring strength using the NordBord: between-session reliability and interlimb asymmetries in professional soccer players. *J Strength Cond Res* 36: 2552–2557, 2022.Available from: https://journals.lww.com/10.1519/JSC.0000000000004303

15. Bishop, C, Read, P, Lake, J, Loturco, I, Dawes, J, Madruga, M, et al. Unilateral isometric squat: test reliability, interlimb asymmetries, and relationships with limb dominance. *J Strength Cond Res* 35: S144–S151, 2021.Available from: https://journals.lww.com/10.1519/JSC.0000000000003079

16. Bourne, MN, Opar, DA, Williams, MD, and Shield, AJ. Eccentric knee flexor strength and risk of hamstring injuries in Rugby Union. *Am J Sports Med* 43: 2663–2670, 2015.Available from: http://journals.sagepub.com/doi/10.1177/0363546515599633

17. Brady, CJ, Harrison, AJ, Flanagan, EP, Haff, GG, and Comyns, TM. A comparison of the isometric midthigh pull and isometric squat: intraday reliability, usefulness, and the

magnitude of difference between tests. *Int J Sports Physiol Perform* 13: 844–852, 2018.Available from: https://journals.humankinetics.com/view/journals/ijspp/13/7/article-p844.xml

18. Bramah, C, Tawiah-Dodoo, J, Rhodes, S, Elliott, JD, and Dos'Santos, T. The sprint mechanics assessment score: a qualitative screening tool for the In-field assessment of sprint running mechanics. *Am J Sports Med* , 2024.Available from: https://journals.sagepub.com/doi/10.1177/03635465241235525
19. Brophy, RH, Stepan, JG, Silvers, HJ, and Mandelbaum, BR. Defending puts the anterior cruciate ligament at risk during soccer. *Sport Heal A Multidiscip Approach* 7: 244–249, 2015.Available from: http://journals.sagepub.com/doi/10.1177/1941738114535184
20. Buchheit, M, Cholley, Y, Nagel, M, and Poulos, N. The effect of body mass on eccentric knee-flexor strength assessed with an instrumented Nordic hamstring device (Nordbord) in football players. *Int J Sports Physiol Perform* 11: 721–726, 2016.Available from: https://journals.humankinetics.com/view/journals/ijspp/11/6/article-p721.xml
21. Buckthorpe, M, Wright, S, Bruce-Low, S, Nanni, G, Sturdy, T, Gross, AS, et al. Recommendations for hamstring injury prevention in elite football: translating research into practice. *Br J Sports Med* 53: 449–456, 2019.
22. Bush, M, Barnes, C, Archer, DT, Hogg, B, and Bradley, PS. Evolution of match performance parameters for various playing positions in the English Premier League. *Hum Mov Sci* 39: 1–11, 2015.Available from: http://www.ncbi.nlm.nih.gov/pubmed/25461429
23. Casanova, N, Palmeira-DE-Oliveira, A, Pereira, A, Crisóstomo, L, Travassos, B, and Costa, AM. Cortisol, testosterone and mood state variation during an official female football competition. *J Sports Med Phys Fitness* 56: 775–81, 2016.Available from: http://www.ncbi.nlm.nih.gov/pubmed/26154730
24. Cassiolas, G, Di Paolo, S, Marchiori, G, Grassi, A, Della Villa, F, Bragonzoni, L, et al. Knee joint contact forces during high-risk dynamic tasks: 90° change of direction and deceleration movements. *Bioengineering* 10: 179, 2023.Available from: https://www.mdpi.com/2306-5354/10/2/179
25. Chavda, S, Turner, AN, Comfort, P, Haff, GG, Williams, S, Bishop, C, et al. A practical guide to analyzing the force-time curve of isometric tasks in excel. *Strength Cond J* 42: 26–37, 2020.Available from:

https://journals.lww.com/10.1519/SSC.0000000000000507

26. Chumanov, ES, Heiderscheit, BC, and Thelen, DG. Hamstring musculotendon dynamics during stance and swing phases of high-speed running. *Med Sci Sport Exerc* 43: 525–532, 2011.Available from: https://journals.lww.com/00005768-201103000-00019
27. Clark, RA, Pua, Y-H, Bower, KJ, Bechard, L, Hough, E, Charlton, PC, et al. Validity of a low-cost laser with freely available software for improving measurement of walking and running speed. *J Sci Med Sport* 22: 212–216, 2019.Available from: https://linkinghub.elsevier.com/retrieve/pii/S1440244018303670
28. Clarke, R, Read, PJ, De Ste Croix, MBA, and Hughes, JD. The deceleration deficit: a novel field-based method to quantify deceleration during change of direction performance. *J Strength Cond Res* 36: 2434–2439, 2022.Available from: https://journals.lww.com/10.1519/JSC.0000000000003856
29. Comfort, P, Dos'Santos, T, Beckham, GK, Stone, MH, Guppy, SN, and Haff, GG. Standardization and methodological considerations for the isometric midthigh pull. *Strength Cond J* 41: 57–79, 2019.Available from: https://journals.lww.com/00126548-201904000-00010
30. Comfort, P, Jones, P, and JMcMahon, J. Performance assessment in strength and conditioning. 1st Editio. London: Routledge, 2018.
31. Comyns, TM, Flanagan, EP, Fleming, S, Fitzgerald, E, and Harper, DJ. Interday reliability and usefulness of a reactive strength index derived from 2 maximal rebound jump tests. *Int J Sports Physiol Perform* 14: 1200–1204, 2019.Available from: https://journals.humankinetics.com/view/journals/ijspp/14/9/article-p1200.xml
32. Constantine, Taberner, Richter, Willett, and Cohen. Isometric posterior chain peak force recovery response following match-play in elite youth soccer players: associations with relative posterior chain strength. *Sports* 7: 218, 2019.Available from: https://www.mdpi.com/2075-4663/7/10/218
33. Coratella, G, Beato, M, and Schena, F. The specificity of the Loughborough Intermittent Shuttle Test for recreational soccer players is independent of their intermittent running ability. *Res Sport Med* 24: 363–374, 2016.Available from: https://www.tandfonline.com/doi/full/10.1080/15438627.2016.1222279
34. Coratella, G, Beato, M, and Schena, F. Correlation between quadriceps and hamstrings inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-players. *Hum Mov Sci* 59: 81–87, 2018.Available from:

https://doi.org/10.1016/j.humov.2018.03.016
35. Cronin, J, McNair, PJ, and Marshall, RN. Developing explosive power: A comparison of technique and training. *J Sci Med Sport* 4: 59–70, 2001.Available from: https://linkinghub.elsevier.com/retrieve/pii/S1440244001800086
36. Cuthbert, M, Comfort, P, Ripley, N, McMahon, JJ, Evans, M, and Bishop, C. Unilateral vs. bilateral hamstring strength assessments: comparing reliability and inter-limb asymmetries in female soccer players. *J Sports Sci* 39: 1481–1488, 2021.Available from: https://www.tandfonline.com/doi/full/10.1080/02640414.2021.1880180
37. Cuthbert, M, Thomas, C, Dos'Santos, T, and Jones, PA. Application of change of direction deficit to evaluate cutting ability. *J Strength Cond Res* 33: 2138–2144, 2019.Available from: https://journals.lww.com/00124278-201908000-00011
38. Datson, N, Drust, B, Weston, M, Jarman, IH, Lisboa, PJ, and Gregson, W. Match physical performance of elite female soccer players during international competition. *J strength Cond Res* 31: 2379–2387, 2017.Available from: http://www.ncbi.nlm.nih.gov/pubmed/27467514
39. Datson, N, Hulton, A, Andersson, H, Lewis, T, Weston, M, Drust, B, et al. Applied physiology of female soccer: an update. *Sports Med* 44: 1225–40, 2014.Available from: http://www.ncbi.nlm.nih.gov/pubmed/24803162
40. Datson, N, Weston, M, Drust, B, Atkinson, G, Lolli, L, and Gregson, W. Reference values for performance test outcomes relevant to English female soccer players. *Sci Med Footb* , 2022.Available from: https://www.tandfonline.com/doi/full/10.1080/24733938.2022.2037156
41. Dawson, L, McErlain-Naylor, SA, Devereux, G, and Beato, M. Practitioner usage, applications, and understanding of wearable GPS and accelerometer technology in team sports. *J Strength Cond Res* , 2024.Available from: https://journals.lww.com/10.1519/JSC.0000000000004781
42. Dos'Santos, T, Jones, PA, Comfort, P, and Thomas, C. Effect of different onset thresholds on isometric midthigh pull force-time variables. *J Strength Cond Res* 31: 3463–3473, 2017.Available from: https://journals.lww.com/00124278-201712000-00025
43. Dos'Santos, T, McBurnie, A, Donelon, T, Thomas, C, Comfort, P, and Jones, PA. A qualitative screening tool to identify athletes with 'high-risk' movement mechanics during cutting: The cutting movement assessment score (CMAS). *Phys Ther Sport* 38:

152–161, 2019.Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466853X19301129

44. Dos'Santos, T, McBurnie, A, Thomas, C, Comfort, P, and Jones, PA. Biomechanical comparison of cutting techniques: a review and practical applications. *Strength Cond J* 41: 40–54, 2019.Available from: https://journals.lww.com/00126548-201908000-00004

45. Dos'Santos, T, Thomas, C, Comfort, P, and Jones, PA. The effect of angle and velocity on change of direction biomechanics: an angle-velocity trade-off. *Sport Med* 48: 2235–2253, 2018.Available from: http://link.springer.com/10.1007/s40279-018-0968-3

46. Dos'Santos, T, Thomas, C, and Jones, PA. Assessing interlimb asymmetries: are we heading in the right direction? *Strength Cond J* 43: 91–100, 2021.Available from: https://journals.lww.com/10.1519/SSC.0000000000000590

47. Dos'Santos, T, Thomas, C, and Jones, PA. The effect of angle on change of direction biomechanics: Comparison and inter-task relationships. *J Sports Sci* 39: 2618–2631, 2021.Available from: https://www.tandfonline.com/doi/full/10.1080/02640414.2021.1948258

48. Doyle, B, Browne, D, and Horan, D. Age-group differences in reactive strength and measures of intra-day reliability in female international footballers. *Int J Strength Cond* 1, 2021.Available from: https://journal.iusca.org/index.php/Journal/article/view/44

49. Drake, D, Kennedy, R, and Wallace, E. Familiarization, validity and smallest detectable difference of the isometric squat test in evaluating maximal strength. *J Sports Sci* 36: 2087–2095, 2018.Available from: https://www.tandfonline.com/doi/full/10.1080/02640414.2018.1436857

50. Duthie, GM, Pyne, DB, Ross, AA, Livingstone, SG, and Hooper, SL. The reliability of ten-meter sprint time using different starting techniques. *J Strength Cond Res* 20: 246, 2006.Available from: http://nsca.allenpress.com/nscaonline/?request=get-abstract&doi=10.1519%2FR-17084.1

51. van Dyk, N, Bahr, R, Burnett, AF, Whiteley, R, Bakken, A, Mosler, A, et al. A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: a prospective cohort study of 413 professional football players. *Br J Sports Med* 51: 1695–1702, 2017.Available from: http://bjsm.bmj.com/lookup/doi/10.1136/bjsports-2017-097754

52. van Dyk, N, Behan, FP, and Whiteley, R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. *Br J Sports Med* 53: 1362–1370, 2019.Available from: https://bjsm.bmj.com/lookup/doi/10.1136/bjsports-2018-100045

53. Emmonds, S, Heyward, O, and Jones, B. The challenge of applying and undertaking research in female sport. *Sport Med - Open* 5: 51, 2019.Available from: https://sportsmedicine-open.springeropen.com/articles/10.1186/s40798-019-0224-x

54. Emmonds, S, Morris, R, Murray, E, Robinson, C, Turner, L, and Jones, B. The influence of age and maturity status on the maximum and explosive strength characteristics of elite youth female soccer players. *Sci Med Footb* 1: 209–215, 2017.Available from: https://www.tandfonline.com/doi/full/10.1080/24733938.2017.1363908

55. Emmonds, S, Sawczuk, T, Scantlebury, S, Till, K, and Jones, B. Seasonal changes in the physical performance of elite youth female soccer players. *J strength Cond Res* , 2018.Available from: http://www.ncbi.nlm.nih.gov/pubmed/30358700

56. Emmonds, S, Scantlebury, S, Murray, E, Turner, L, Robsinon, C, and Jones, B. Physical characteristics of elite youth female soccer players characterized by maturity status. *J strength Cond Res* , 2018.Available from: http://www.ncbi.nlm.nih.gov/pubmed/30199446

57. Eustace, SJ, Page, RM, and Greig, M. Isokinetic strength differences between elite senior and youth female soccer players identifies training requirements. *Phys Ther Sport* 39: 45–51, 2019.Available from: https://linkinghub.elsevier.com/retrieve/pii/S1466853X19300446

58. FIFA. Physical Analysis of the FIFA Women's World Cup France 2019^{TM}. https://img.fifa.com/image/upload/zijqly4oednqa5gf, 2019.

59. Filter-Ruger, A, Gantois, P, S. Henrique, R, Olivares-Jabalera, J, Robles-Rodríguez, J, Santalla, A, et al. How does curve sprint evolve across different age-categories in soccer players? *Biol Sport* 39: 53–58, 2022.Available from: https://www.termedia.pl/doi/10.5114/biolsport.2022.102867

60. Fílter, A, Beltrán-Garrido, V, Dos'Santos, T, Romero-Rodríguez, D, Requena, B, Loturco, I, et al. The relationship between performance and asymmetries in different multidirectional sprint tests in soccer players. *J Hum Kinet* 79: 155–164, 2021.Available from: https://jhk.termedia.pl/The-Relationship-Between-Performance-and-Asymmetries-in-Different-Multidirectional,158620,0,2.html

61. Filter, A, Olivares-Jabalera, J, Santalla, A, Morente-Sánchez, J, Robles-Rodríguez, J, Requena, B, et al. Curve sprinting in soccer: kinematic and neuromuscular analysis. *Int J Sports Med* , 2020.Available from: http://www.thieme-connect.de/DOI/DOI?10.1055/a-1144-3175
62. Fílter, A, Olivares, J, Santalla, A, Nakamura, FY, Loturco, I, and Requena, B. New curve sprint test for soccer players: Reliability and relationship with linear sprint. *J Sports Sci* 38: 1320–1325, 2020.Available from: https://www.tandfonline.com/doi/full/10.1080/02640414.2019.1677391
63. Gonzalo-Skok, O, Dos'Santos, T, and Bishop, C. Assessing limb dominance and interlimb asymmetries over multiple angles during change of direction speed tests in Basketball players. *J Strength Cond Res* 37: 2423–2430, 2023.Available from: https://journals.lww.com/10.1519/JSC.0000000000004558
64. Greig, M and Langley, B. Exploring the issue of 'functionality' in isokinetic dynamometry. *Res Sport Med* 1–6, 2023.Available from: https://www.tandfonline.com/doi/full/10.1080/15438627.2023.2260521
65. Guppy, SN, Nagatani, T, Poon, WCK, Kendall, KL, Lake, JP, and Haff, GG. The stability of the deadlift three repetition maximum. *Int J Sports Sci Coach* 19: 812–821, 2024.Available from: https://journals.sagepub.com/doi/10.1177/17479541231174316
66. Harkness-Armstrong, A, Till, K, Datson, N, and Emmonds, S. Whole and peak physical characteristics of elite youth female soccer match-play. *J Sports Sci* 39: 1320–1329, 2021.Available from: https://www.tandfonline.com/doi/full/10.1080/02640414.2020.1868669
67. Harper, DJ, McBurnie, AJ, Santos, TD, Eriksrud, O, Evans, M, Cohen, DD, et al. Biomechanical and neuromuscular performance requirements of horizontal deceleration: a review with implications for random intermittent multi-directional sports. *Sport Med* 52: 2321–2354, 2022.Available from: https://link.springer.com/10.1007/s40279-022-01693-0
68. Harper, DJ, Morin, J-B, Carling, C, and Kiely, J. Measuring maximal horizontal deceleration ability using radar technology: reliability and sensitivity of kinematic and kinetic variables. *Sport Biomech* 1–17, 2020.Available from: http://www.ncbi.nlm.nih.gov/pubmed/32731845
69. Haugen, T and Buchheit, M. Sprint running performance monitoring: Methodological and practical considerations. *Sports Med* 46: 641–56, 2016.Available from: http://www.ncbi.nlm.nih.gov/pubmed/26660758

70. Havens, KL and Sigward, SM. Cutting mechanics: relation to performance and anterior cruciate ligament injury risk. *Med Sci Sports Exerc* 47: 818–24, 2015.Available from: https://journals.lww.com/00005768-201504000-00018
71. Hostrup, M and Bangsbo, J. Performance adaptations to intensified training in top-level football. *Sport Med* 53: 577–594, 2023.Available from: https://link.springer.com/10.1007/s40279-022-01791-z
72. Impellizzeri, FM, Bizzini, M, Rampinini, E, Cereda, F, and Maffiuletti, NA. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clin Physiol Funct Imaging* 28: 113–9, 2008.Available from: http://www.ncbi.nlm.nih.gov/pubmed/18070123
73. Impellizzeri, FM, Rampinini, E, and Marcora, SM. Physiological assessment of aerobic training in soccer. *J Sports Sci* 23: 583–592, 2005.Available from: http://www.ncbi.nlm.nih.gov/pubmed/16195007
74. Jiménez-Reyes, P, Garcia-Ramos, A, Párraga-Montilla, JA, Morcillo-Losa, JA, Cuadrado-Peñafiel, V, Castaño-Zambudio, A, et al. Seasonal changes in the sprint acceleration force-velocity profile of elite male soccer players. *J Strength Cond Res* 36: 70–74, 2022.Available from: https://journals.lww.com/10.1519/JSC.0000000000003513
75. Johnston, N. Women's World Cup 2023: Record attendance of almost two million. *BBC Sport* August, 2023.
76. Jones, P and Dos'Santos, T. Multidirectional Speed in Sport: Research to Application. New York: Routledge, 2023.Available from: https://www.taylorfrancis.com/books/9781003267881
77. Jones, P and Dos Santos, T. Multi-directional speed in sport research to application. London: Routledge, 2023.
78. Jones, P, Thomas, C, Dos'Santos, T, McMahon, J, and Graham-Smith, P. The role of eccentric strength in 180° turns in female soccer players. *Sports* 5: 42, 2017.Available from: http://www.mdpi.com/2075-4663/5/2/42
79. Jones, PA, Dos'Santos, T, McMahon, JJ, and Graham-Smith, P. Contribution of eccentric strength to cutting Performance in female soccer players. *J Strength Cond Res* 36: 525–533, 2022.Available from: https://journals.lww.com/10.1519/JSC.0000000000003433
80. Jones, PA, Herrington, L, and Graham-Smith, P. Braking characteristics during cutting and pivoting in female soccer players. *J Electromyogr Kinesiol* 30: 46–54,

2016.Available from: https://linkinghub.elsevier.com/retrieve/pii/S1050641116300463

81. Jones, PA, Herrington, LC, and Graham-Smith, P. Technique determinants of knee abduction moments during pivoting in female soccer players. *Clin Biomech* 31: 107–112, 2016.Available from: https://linkinghub.elsevier.com/retrieve/pii/S0268003315002533

82. Kirkendall, DT and Krustrup, P. Studying professional and recreational female footballers: A bibliometric exercise. *Scand J Med Sci Sports* 32: 12–26, 2022.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sms.14019

83. Kristjánsdóttir, H, Jóhannsdóttir, KR, Pic, M, and Saavedra, JM. Psychological characteristics in women football players: Skills, mental toughness, and anxiety. *Scand J Psychol* 60: 609–615, 2019.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sjop.12571

84. Lockie, R, Dawes, J, and Jones, M. Relationships between linear speed and lower-body power with change-of-direction speed in national collegiate athletic association divisions I and II women soccer athletes. *Sports* 6: 30, 2018.Available from: http://www.mdpi.com/2075-4663/6/2/30

85. Lucarno, S, Zago, M, Buckthorpe, M, Grassi, A, Tosarelli, F, Smith, R, et al. Systematic video analysis of anterior cruciate ligament injuries in professional female soccer players. *Am J Sports Med* 49: 1794–1802, 2021.Available from: http://journals.sagepub.com/doi/10.1177/03635465211008169

86. Madsen, EE, Hansen, T, Thomsen, SD, Panduro, J, Ermidis, G, Krustrup, P, et al. Can psychological characteristics, football experience, and player status predict state anxiety before important matches in Danish elite-level female football players? *Scand J Med Sci Sports* 32: 150–160, 2022.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sms.13881

87. Manson, SA, Brughelli, M, and Harris, NK. Physiological characteristics of international female soccer players. *J strength Cond Res* 28: 308–18, 2014.Available from: http://www.ncbi.nlm.nih.gov/pubmed/24476742

88. Marcote-Pequeño, R, García-Ramos, A, Cuadrado-Peñafiel, V, González-Hernández, JM, Gómez, MÁ, and Jiménez-Reyes, P. Association between the force–velocity profile and performance variables obtained in jumping and sprinting in elite female soccer players. *Int J Sports Physiol Perform* 14: 209–215, 2019.Available from: https://journals.humankinetics.com/doi/10.1123/ijspp.2018-0233

89. Marshall, BM, Franklyn-Miller, AD, King, EA, Moran, KA, Strike, SC, and Falvey,

ÉC. Biomechanical factors associated with time to complete a change of direction cutting maneuver. *J Strength Cond Res* 28: 2845–2851, 2014.Available from: https://journals.lww.com/00124278-201410000-00019

90. Martínez-Hernández, D, Quinn, M, and Jones, P. Most common movements preceding goal scoring situations in female professional soccer. *Sci Med Footb* 1–9, 2023.Available from: https://www.tandfonline.com/doi/full/10.1080/24733938.2023.2214106

91. McBurnie, AJ and Dos'Santos, T. Multidirectional speed in youth soccer players: theoretical underpinnings. *Strength Cond J* 44: 15–33, 2022.Available from: https://journals.lww.com/10.1519/SSC.0000000000000658

92. McCall, A, Nedelec, M, Carling, C, Le Gall, F, Berthoin, S, and Dupont, G. Reliability and sensitivity of a simple isometric posterior lower limb muscle test in professional football players. *J Sports Sci* 33: 1298–1304, 2015.Available from: http://www.tandfonline.com/doi/full/10.1080/02640414.2015.1022579

93. McMahon, J, Rej, S, and Comfort, P. Sex differences in countermovement jump phase characteristics. *Sports* 5: 8, 2017.Available from: http://www.mdpi.com/2075-4663/5/1/8

94. McMahon, JJ, Lake, JP, Stratford, C, and Comfort, P. A proposed method for evaluating drop jump performance with one force platform. *Biomechanics* 1: 178–189, 2021.Available from: https://www.mdpi.com/2673-7078/1/2/15

95. McMahon, JJ, Suchomel, TJ, Lake, JP, and Comfort, P. Understanding the key phases of the countermovement jump force-time curve. *Strength Cond J* 40: 96–106, 2018.Available from: https://journals.lww.com/00126548-201808000-00010

96. Mohr, M, Krustrup, P, and Bangsbo, J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci* 21: 519–28, 2003.Available from: http://www.tandfonline.com/doi/abs/10.1080/0264041031000071182

97. Morgans, R, Di Michele, R, and Drust, B. Soccer match play as an important component of the power-training stimulus in Premier League players. *Int J Sports Physiol Perform* 13: 665–667, 2018.Available from: http://journals.humankinetics.com/doi/10.1123/ijspp.2016-0412

98. Mujika, I, Santisteban, J, Impellizzeri, FM, and Castagna, C. Fitness determinants of success in men's and women's football. *J Sports Sci* 27: 107–114, 2009.Available from: http://www.tandfonline.com/doi/abs/10.1080/02640410802428071

99. Myhill, N, Weaving, D, Barrett, S, King, R, and Emmonds, S. A multi-club analysis of the locomotor training characteristics of elite female soccer players. *Sci Med Footb* 6: 572–580, 2022.Available from: https://www.tandfonline.com/doi/full/10.1080/24733938.2022.2114603

100. Nagahara, R, Naito, H, Miyashiro, K, Morin, JB, and Zushi, K. Traditional and ankle-specific vertical jumps as strength-power indicators for maximal sprint acceleration. *J Sports Med Phys Fitness* 54: 691–9, 2014.Available from: http://www.ncbi.nlm.nih.gov/pubmed/24739258

101. Needham, C and Herrington, L. Cutting movement assessment scores during anticipated and unanticipated 90-degree sidestep cutting manoeuvres within female professional footballers. *Sports* 10: 128, 2022.Available from: https://www.mdpi.com/2075-4663/10/9/128

102. Nimphius, S, Callaghan, SJ, Bezodis, NE, and Lockie, RG. Change of direction and agility tests: Challenging our current measures of performance. *Strength Cond J* 40: 26–38, 2018.Available from: https://journals.lww.com/00126548-201802000-00004

103. Nonnato, A, Hulton, AT, Brownlee, TE, and Beato, M. The effect of a single session of plyometric training per week on fitness parameters in professional female soccer players: a randomized controlled trial. *J Strength Cond Res* 36: 1046–1052, 2022.Available from: http://journals.lww.com/10.1519/JSC.0000000000003591

104. Okholm Kryger, K, Wang, A, Mehta, R, Impellizzeri, FM, Massey, A, and McCall, A. Research on women's football: a scoping review. *Sci Med Footb* 1–10, 2021.Available from: https://www.tandfonline.com/doi/full/10.1080/24733938.2020.1868560

105. Opar, DA, Williams, MD, Timmins, RG, Hickey, J, Duhig, SJ, and Shield, AJ. Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Med Sci Sport Exerc* 47: 857–865, 2015.Available from: https://journals.lww.com/00005768-201504000-00024

106. Ostenberg, A, Roos, E, Ekdahl, C, and Roos, H. Isokinetic knee extensor strength and functional performance in healthy female soccer players. *Scand J Med Sci Sports* 8: 257–64, 1998.

107. Panduro, J, Ermidis, G, Røddik, L, Vigh-Larsen, JF, Madsen, EE, Larsen, MN, et al. Physical performance and loading for six playing positions in elite female football: full-game, end-game, and peak periods. *Scand J Med Sci Sports* 32: 115–126, 2022.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sms.13877

108. Di Paolo, S, Zaffagnini, S, Tosarelli, F, Aggio, F, Bragonzoni, L, Grassi, A, et al. A

2D qualitative movement assessment of a deceleration task detects football players with high knee joint loading. *Knee Surgery, Sport Traumatol Arthrosc* 29: 4032–4040, 2021.Available from: https://link.springer.com/10.1007/s00167-021-06709-2

109. Pardos-Mainer, E, Lozano, D, Torrontegui-Duarte, M, Cartón-Llorente, A, and Roso-Moliner, A. Effects of strength vs. plyometric training programs on Vertical Jumping, linear sprint and change of direction speed performance in female soccer players: a systematic review and meta-analysis. *Int J Environ Res Public Health* 18: 401, 2021.Available from: https://www.mdpi.com/1660-4601/18/2/401

110. Payton, C and Bartlett, R (eds). Biomechanical evaluation of movement in sport and exercise. The Britis. London: Routledge, 2008.

111. Pedley, JS, Lloyd, RS, Read, PJ, Moore, IS, Myer, GD, and Oliver, JL. A novel method to categorize stretch-shortening cycle performance across maturity in youth soccer players. *J Strength Cond Res* 36: 2573–2580, 2022.Available from: https://journals.lww.com/10.1519/JSC.0000000000003900

112. Rhodes, D, Jeffery, J, Brook-Sutton, D, and Alexander, J. Test-retest reliability of the isometric soleus strength test in elite male academy footballers. *Int J Sports Phys Ther* 17, 2022.Available from: https://ijspt.scholasticahq.com/article/31047-test-retest-reliability-of-the-isometric-soleus-strength-test-in-elite-male-academy-footballers

113. Ripley, NJ, Fahey, J, Cuthbert, M, McMahon, JJ, and Comfort, P. Rapid force generation during unilateral isometric hamstring assessment: reliability and relationship to maximal force. *Sport Biomech* 1–12, 2023.Available from: http://www.ncbi.nlm.nih.gov/pubmed/37942715

114. Roe, M, Delahunt, E, McHugh, M, Gissane, C, Malone, S, Collins, K, et al. Association between eccentric knee flexor strength and hamstring injury risk in 185 elite Gaelic football players. *Scand J Med Sci Sports* 30: 515–522, 2020.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sms.13588

115. Ryan, C, Uthoff, A, McKenzie, C, and Cronin, J. New perspectives of the traditional and modified 5-0-5 change of direction test. *Strength Cond J* 45: 83–92, 2023.Available from: https://journals.lww.com/10.1519/SSC.0000000000000723

116. Samozino, P, Peyrot, N, Edouard, P, Nagahara, R, Jimenez-Reyes, P, Vanwanseele, B, et al. Optimal mechanical force-velocity profile for sprint acceleration performance. *Scand J Med Sci Sports* 32: 559–575, 2022.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sms.14097

117. Sassi, RH, Dardouri, W, Yahmed, MH, Gmada, N, Mahfoudhi, ME, and Gharbi, Z.

Relative and absolute reliability of a modified agility T-test and its relationship with vertical jump and straight sprint. *J Strength Cond Res* 23: 1644–1651, 2009.Available from: https://journals.lww.com/00124278-200909000-00003

118. Schache, AG, Dorn, TW, Blanch, PD, Brown, NAT, and Pandy, MG. Mechanics of the human hamstring muscles during sprinting. *Med Sci Sports Exerc* 44: 647–58, 2012.Available from: https://journals.lww.com/00005768-201204000-00011
119. Silva, AF, Oliveira, R, Raya-González, J, van den Hoek, D, Akyildiz, Z, Yıldız, M, et al. Difference between preferred and non-preferred leg in peak speed, acceleration, and deceleration variables and their relationships with the change-of-direction deficit. *Sci Rep* 12: 21440, 2022.Available from: https://www.nature.com/articles/s41598-022-26118-w
120. Spiteri, T, Newton, RU, Binetti, M, Hart, NH, Sheppard, JM, and Nimphius, S. Mechanical determinants of faster change of direction and agility performance in female basketball athletes. *J Strength Cond Res* 29: 2205–2214, 2015.Available from: https://journals.lww.com/00124278-201508000-00016
121. Spiteri, T, Nimphius, S, Hart, NH, Specos, C, Sheppard, JM, and Newton, RU. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. *J Strength Cond Res* 28: 2415–2423, 2014.Available from: https://journals.lww.com/00124278-201409000-00004
122. Stratford, C, Dos'Santos, T, and McMahon, JJ. The 10/5 Repeated Jumps Test: Are 10 Repetitions and Three Trials Necessary? *Biomechanics* 1: 1–14, 2020.Available from: https://www.mdpi.com/2673-7078/1/1/1
123. Straub, RK, Horgan, A, and Powers, CM. Estimation of vertical ground reaction force parameters during athletic tasks using 2D video. *Gait Posture* 90: 483–488, 2021.Available from: https://linkinghub.elsevier.com/retrieve/pii/S0966636221004860
124. Svensson, M and Drust, B. Testing soccer players. *J Sports Sci* 23: 601–18, 2005.Available from: http://www.tandfonline.com/doi/abs/10.1080/02640410400021294
125. The FA. The gameplan for growth. The FA's strategy for women's and girls' football: 2017 - 2020. Available at: https://www.thefa.com/ news/2017/mar, 2020.Available from: file:///Users/marcobeato/Downloads/fawomensstrategydocfinal-13317.pdf
126. Thomas, C, Dos'santos, T, Cuthbert, M, Fields, C, and Jones, PA. The effect of limb preference on braking strategy and knee joint mechanics during pivoting in female soccer players. *Sci Med Footb* 4: 30–36, 2020.Available from:

https://www.tandfonline.com/doi/full/10.1080/24733938.2019.1667020

127. Timmins, RG, Bourne, MN, Shield, AJ, Williams, MD, Lorenzen, C, and Opar, DA. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. *Br J Sports Med* 50: 1524–1535, 2016.Available from: https://bjsm.bmj.com/lookup/doi/10.1136/bjsports-2015-095362
128. Verbruggen, FF, Hank, M, Miřátský, P, Malý, T, and Zahálka, F. Lower limb strength and training experience in elite and sub-elite female footballers. *Isokinet Exerc Sci* 1–10, 2023.Available from: https://www.medra.org/servlet/aliasResolver?alias=iospress&doi=10.3233/IES-230038
129. Vescovi, JD, Fernandes, E, and Klas, A. Physical demands of women's soccer matches: a perspective across the developmental spectrum. *Front Sport Act Living* 3, 2021.Available from: https://www.frontiersin.org/articles/10.3389/fspor.2021.634696/full
130. Westheim, F, Gløersen, Ø, Harper, D, Laugsand, H, and Eriksrud, O. Reliability of phase-specific outcome measurements in change-of-direction tests using a motorized resistance device. *Front Sport Act Living* 5, 2023.Available from: https://www.frontiersin.org/articles/10.3389/fspor.2023.1212414/full
131. Wiesinger, H, Gressenbauer, C, Kösters, A, Scharinger, M, and Müller, E. Device and method matter: A critical evaluation of eccentric hamstring muscle strength assessments. *Scand J Med Sci Sports* 30: 217–226, 2020.Available from: https://onlinelibrary.wiley.com/doi/10.1111/sms.13569
132. Wild, JJ, Bezodis, IN, North, JS, and Bezodis, NE. Characterising initial sprint acceleration strategies using a whole-body kinematics approach. *J Sports Sci* 40: 203–214, 2022.Available from: https://www.tandfonline.com/doi/full/10.1080/02640414.2021.1985759
133. Zhang, Q, Dellal, A, Chamari, K, Igonin, P-H, Martin, C, and Hautier, C. The influence of short sprint performance, acceleration, and deceleration mechanical properties on change of direction ability in soccer players—A cross-sectional study. *Front Physiol* 13, 2022.Available from: https://www.frontiersin.org/articles/10.3389/fphys.2022.1027811/full

Figures and tables

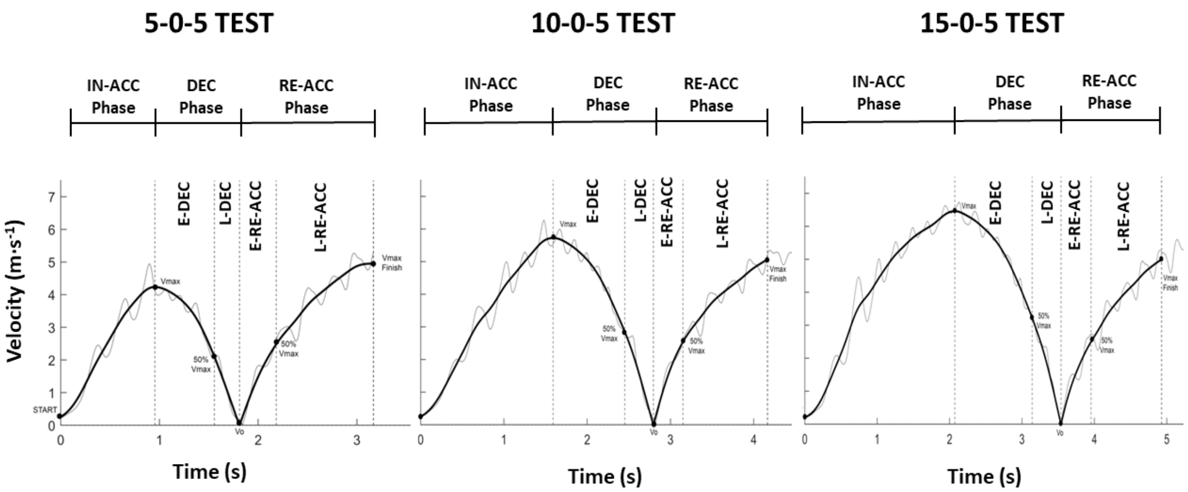


Figure 1. Example change of direction velocity time profiles in 180-degree change of direction tests with different approach distances, enabling identification and evaluation of change of direction sub-phase (i.e., initial acceleration, deceleration, turn and re-acceleration) performances (modified from Westheim et al., 2023). 5-0-5 = 5m approach prior to turn, 10-0-5 = 10m approach prior to turn, 15-0-5 = 15m approach prior to turn, IN-ACC = initial-acceleration, DEC = deceleration, RE-ACC = re-acceleration, E-DEC = early deceleration, L-DEC = late deceleration, E-RE-ACC = early re-acceleration, L-RE-ACC = late re-acceleration.

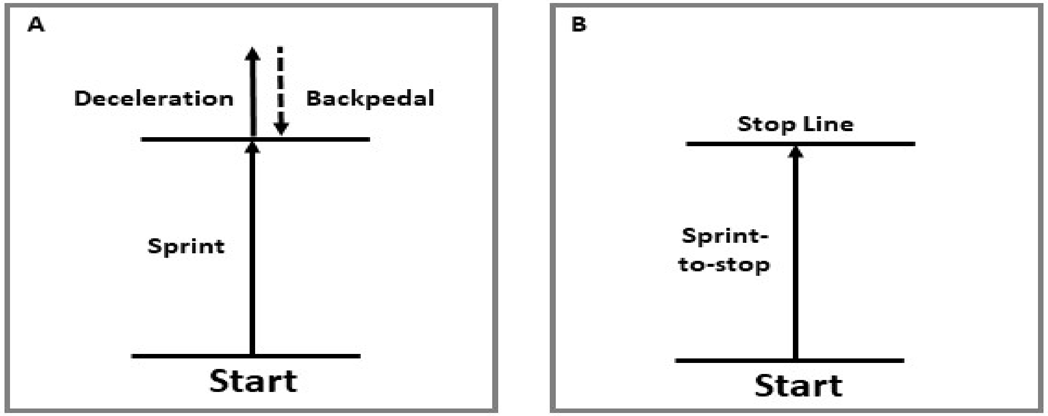


Figure 2. Acceleration-deceleration ability (ADA) test protocols using either (A) maximal sprint across a pre-set distance before decelerating maximally or (B) maximal sprint followed by deceleration to a stop at a pre-set distance.

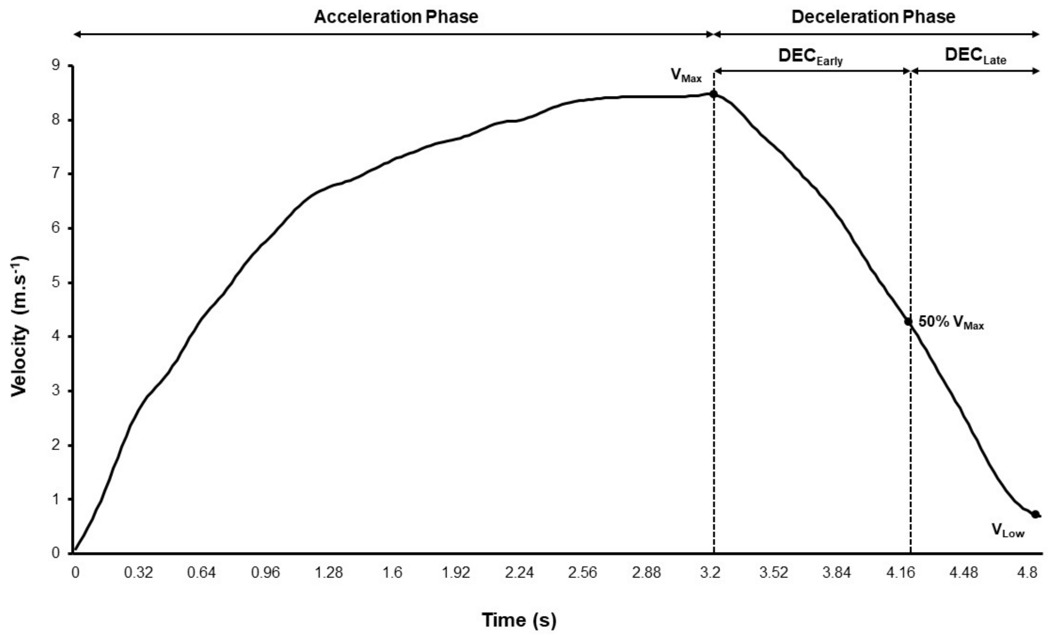
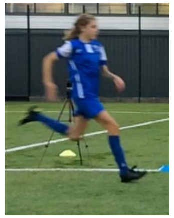
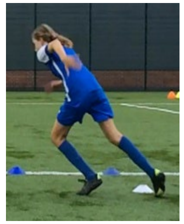
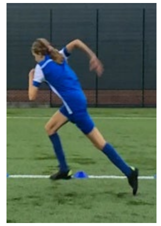


Figure 3. Velocity-time profile from an acceleration-deceleration ability (ADA) test.

TABLE 1. The technical framework for a 505-test including required muscle strength qualities and potential assessments.

Task	**Traditional 505 test (180° Turn)**							
Phase	Initiation ('Approach')		Preparation		Execution (''plant'' step)		Re-acceleration	
Sub-phases	Ground Contact	Flight	TD PFC	End of PFC (MKF)	TD to MKF	MKF to Take-off	Ground contact	Flight
Photo sequence								
Critical Features	• Slight torso lean. • Contra-lateral limb movement • Minimize TD distance • Minimal knee & ankle flexion • Extend hip, knee & ankle at toe-off • Opposite swing leg – knee flexion/ ankle dorsi-flexion to high knee lift position	• Slight torso lean • Contra-lateral limb movement • Rapid limb switching with optimal limb folding mid swing to reduce moment of inertia. • 'Pawing' motion from hip in preparation for ground contact during late-stage flight	• Lean (torso) back • Foot in front of CM at TD (Heel contact)	• Lower CM position through rapid hip (~75°), knee (~120°) and ankle flexion at end of contact • Trunk now leaning forward • Possible pre-rotation of pelvis (postural adjustments) / external rotation of PFC lower-limb to reduce the redirection requirements for the FFC	• Trunk upright • Foot ahead of CM • Period of dual-support - helps ↓'Plant' foot load & facilitates re-acceleration out of turn. • Hip, knee & ankle dorsi-flexion • Avoid foot rotation & knee valgus	• Trunk lean & pelvis rotates into direction into direction of travel • Rapid Extend hip, knee & ankle • Avoid double foot contact (e.g., 'hop' - typically associated with ineffective PFC braking)	• Trunk lean into directional of travel • Shorter steps • Foot contact behind / under CM • Extend hip, knee & ankle at take-off (Period of dual-support allows effective position for re-acceleration) to project horizontally	• Trunk lean into intended direction of travel • Vigorous arm drive • Low limb recovery in preparation for subsequent acceleration step
Aim	Produce highest controllable velocity		Reduce velocity & prepare for optimal position for 'plant' step		Execute directional change safely & efficiently		Increase velocity into reverse direction	
Movement Principles	FP, Limb speed - swing leg, SSC, WBRS: SL × SF	A-R WBRS: SL × SF	↑ TD distance to ↑ braking S-A trade-off, FP	FP, ROM – ↑lower limb flexion, braking force applied for longer to ↓ momentum	COD, SSC, WBR, Stability (↓CM/ ↔ Base), FP	FP, ROM, SJM, WBR, Stability (↓CM/ ↔ Base)	↓ TD distance (Stability) ROM, SJM, WBRS: SL × SF, FP	A-R, WBRS: SL × SF

Underpinning Muscle Strength qualities	Fast reactive strength RFD / Impulse	Eccentric strength (hamstrings late / terminal swing) Isometric hamstring strength / RFD / Impulse	Eccentric strength / RFD / Impulse (Knee extensors & Flexors; hip extensors)	Eccentric strength/ RFD / Impulse (Knee extensors & Flexors; hip extensors)	Eccentric strength (Knee extensors & Flexors; hip extensors) Slow SSC ability	Slow SSC ability Concentric strength (lower limb extensors) Isometric strength & RFD	Concentric strength (lower limb extensors) RFD	Concentric (lower limb extensor) & hip flexor strength (to aid limb recovery)
Potential Assessments	Drop Jump; 10/5 Repeated Jump Test; BOSCO Isometric mid-thigh pull Single joint-isometric hip and ankle extensors	Isokinetic Dynamometry NordBoard Isometric 90/90 or 30/30	Isokinetic Dynamometry NordBoard		Isokinetic Dynamometry NordBoard	Countermovement Jump (for COD of longer contact time) Isometric mid-thigh pull Single joint-isometric hip and ankle extensors	Squat Jump 1RM Back Squat Isometric mid-thigh pull Single joint-isometric hip and ankle extensors	

Note: PFC = penultimate foot contact; FFC = final foot contact; TD = touchdown; COD = change of direction; CM = center of mass; MKF = max knee flexion; SL = step length; SF = step frequency; RFD = rate of force development.

Movement principles based on Lees (2008): force production (FP), to produce maximal effective force a firm base is required to push off; limb speed is when a limb will rotate quicker if it is more compact (flexed and held close to the axis of rotation); stretch-shorten cycle (SSC), enhancement of concentric force production following a prior eccentric muscle action providing minimal delay between each; whole body running speed (WBRS) is influenced be the interaction of step length and step frequency; action – reaction (A-R): simultaneous movements of opposing limbs, contra-lateral limb movement of the arms is required to maintain angular momentum about the long axis of the body; change of direction (COD), to facilitate a change of direction the foot needs to be placed to generate horizontal force perpendicular to the initial direction of travel; range of motion (ROM) to increase or decrease momentum (and thus, velocity) force (propulsion or braking) needs to be applied for longer (impulse = force × time); simultaneous joint movements (SJM) to produce maximal propulsive force through extending hip, knee and ankle simultaneously; speed-accuracy trade-off (S-A trade-off) - when greater accuracy is required velocity is reduced; whole body rotation (WBR), arms close to the body to reduce whole body moment of inertia for faster rotation during the directional change. Stability – objects are more stable with a low center of mass and wide base of support; conversely, performers can take advantage of instability (CM ahead of the base of support) to increase (angular) momentum into the intended direction of travel such as during early acceleration steps.

Table 2. Recommendations for selected on-field tests: rationale, advantages, and disadvantages.

Test	Rationale	Advantages	Disadvantages
Chane of direction speed testing and 505 COD	- The ability to perform rapid changes of direction is critical in numerous court- and field-based sports, including football. - Football players frequently encounter scenarios where they must evade opponents, switch directions, and maintain control of the ball. - The 505 COD test is commonly used to assess COD ability in the horizontal plane. - Unlike other CODs tests, the 505 Test uses a single 180-degree change of direction, potentially distinguishing between dominant and non-dominant leg performances.	- The 505 COD test is widely used due to its straightforward setup and minimal cost. - It can be used to distinguish between dominant and non-dominant legs, and it can be useful for assessing asymmetry. - Requires no reactive ability, making it a measure of CODs rather than agility. - The 505 COD can be performed with different approach distances (i.e., 5m, 10m, 15m) and is commonly used to obtain more detailed insights on a player's COD performance	- It accurately measures the change of direction speed over short sprint distances, while other tests could be more suitable to assess higher COD speed. - Unlike true agility tests, the 505 COD test does not incorporate perceptual cognitive abilities or reactive movements.
Horizontal deceleration testing	- Football players frequently encounter scenarios where they must evade opponents, switch directions, and maintain control of the ball. Therefore,	- Field-based technologies that facilitate continuous velocity measurements should be used to obtain reliable deceleration performance measures such as average and peak deceleration,	- Equipment and space requirements to obtain accurate data. - Time to execute the assessment could be a limiting factor in football settings.

	horizontal acceleration and deceleration capacities are critical. - Horizontal deceleration can also be assessed using an ADA test where a player either (a) sprints maximally across a pre-set distance before then decelerating maximally, or (b) sprints maximally and decelerates to a stop at a pre-set distance (see Figure 2).	distance and time-to-stop. Figure 3 illustrates an example velocity-time profile measured using a radar device (Stalker ATS II) from an ADA test.	- Proper execution of the test demands technical proficiency to ensure reliable data.
Linear sprinting	- Linear sprinting refers to straight-ahead sprinting in a single direction without any significant changes in trajectory. - In football, linear sprints are crucial for various scenarios, such as chasing down opponents, breaking away from defenders, or reaching a ball quickly. - The primary rationale for emphasizing linear sprinting is to enhance acceleration and maximal velocity, which are essential for success in match situations	- The gold standard method to assess linear sprinting is an automated system with pressure-sensitive starting blocks and high-resolution cameras. However, such systems are impractical in most applied settings due to their high cost. - More cost-effective solutions such as hand-held systems, radar guns, photocell systems, GNSS and video analysis are recommended.	- Stopwatches are simple to use but are limited by the reaction time of the individual and are therefore not recommended. - The use of dual-beam systems (as opposed to single beam) is recommended as they minimize the likelihood of a false signal from an outstretched arm or leg, as opposed to the participant's torso. - Photocell systems assess average speed, but unlike radar guns and GNSS, they are not suitable for measuring peak speed or providing instantaneous speed profiles.
Curved sprinting	- Curved sprinting refers to sprinting with trajectories that involve changes in direction, such as arced runs, swerves, and curved paths.	- Curved sprints allow players to cover ground while maintaining speed, especially when navigating around	- Curved sprints impose different neuromuscular, mechanical, and bioenergetic demands on the inside and outside legs.

	- In football, players frequently perform curved sprints during match play to evade opponents, track the ball, or strategically position themselves. - Approximately 85% of actions performed at maximum velocity in professional football leagues are curvilinear sprints.	opponents or positioning themselves optimally. - Testing and training curvilinear sprinting alongside traditional linear sprints can help identify players who need further development in this specific skill. - A specialized sprint test tailored for football players was previously developed (see text). This assessment leverages the curvature of the penalty area on a standard football field, encompassing 17 meters.	- The reliability of this curvilinear sprint test was verified in male but not in female players. - An intra-class correlation coefficient ranging from 0.75 to 0.96, was found; therefore, a familiarisation process is needed to obtain reliable data. - Skills required for curvilinear and straight-line sprinting exhibit a certain degree of independence from one another. Consequently, we suggest the inclusion of both linear and curvilinear sprinting tests within the assessment batteries.

COD: Change of direction; ADA: Acceleration-deceleration ability; GNSS: global navigation satellite systems;

Table 3. Recommendations for selected off-field tests: rationale, advantages, and disadvantages.

Test	Rationale	Advantages	Disadvantages
Isometric mid-thigh pull (IMTP)	- MTP provides a reliable and valid measure of maximum multi-joint isometric strength and rapid force production. - When performed on a force plate, the IMTP quantifies peak force, relative force, RFD, and time to peak force. - The IMTP has been found to associate with vertical jumps, sprints, and multidirectional speed performance.	- IMTP performance variables correlate with actions like vertical jumps and sprint speed. - IMTP is a safer alternative to traditional 1RM testing. It requires a low training experience. - IMTP and isometric exercises can be used in training programs to develop strength, power, and tendon stiffness.	- IMTP assesses isometric strength only and does not capture dynamic strength or power. - Equipment and space requirements: performing IMTP requires access to a fixed barbell and a force plate for accurate measurements. - Proper execution of IMTP demands technical proficiency to ensure reliable data.
Isometric hamstring test	The isometric hamstring test assesses the strength and function of the hamstring muscles. - It involves holding a static position without movement, specifically targeting the hamstring group. - Practitioners use this test to evaluate hamstring strength, especially after injuries or during rehabilitation.	- Isometric tests are safer than dynamic movements, reducing the risk of re-injury during assessment. - By quantifying the force produced during the isometric contraction, clinicians obtain objective data. - Isometric testing can identify subtle weaknesses before they lead to significant functional deficits.	- The test only evaluates static strength, not dynamic muscle function. - Equipment and Space Requirements: Proper execution requires access to a force plate or other measurement tools. - Correct positioning and athlete's effort influence results, demanding technical proficiency. - Isometric testing does not replicate real-world movements or sports actions.

	- Isometric testing provides valuable information about muscle function and potential weaknesses.	- Results guide practitioners in determining when athletes are ready for more intense exercises.	
Countermovement (CMJ) and squat jump (SJ)	- The CMJ is a vertical jump test where an athlete quickly squats to a self-selected depth and then jumps as high as possible. - It serves as a measure of explosive lower-body power and is widely used by coaches and researchers. - The CMJ can be performed with or without an arm swing, with the arm-swing version yielding higher performance. - Various measurement tools, including contact mats, force platforms, and high-speed cameras, provide valid and reliable CMJ data. - The SJ involves jumping vertically from a static squat position without any countermovement. It specifically assesses lower limb explosive power and strength. SJ performance is often measured using force platforms or other accurate tools.	- The CMJ and SJ are two of the most reliable tests for lower-body power compared to other jump tests. - CMJ and SJ results relate to sprint performances, maximal strength, and explosive strength. - Including an arm swing can boost CMJ performance by ≥ 10%.	- Proper execution demands access to force platforms or other measurement tools. - Without an arm swing, the squat jump does not fully replicate real-world movements. - SJ does not capture the full spectrum of lower-body power (limited SSC) as the CMJ does.

Drop Jump (DJ)	- The DJ is a fitness test that assesses leg strength and power. During this test, the athlete drops off a box and immediately performs a maximal vertical jump. - It involves an aggressive eccentric-concentric muscle action, utilizing stored elastic energy through the SSC. Incremental DJ test can be used for measuring reactive leg strength, where the athlete jumps after dropping from various heights.	- The DJ measures explosive force generated by the lower limbs. - It provides insights into an athlete's ability to utilize stored energy during rapid movements. - This test can be used to assess the risk of anterior cruciate ligament injuries.	- Standard-size boxes may not be readily available and might need custom fabrication. - Results can be affected by body position during take-off and landing. - If an athlete bends their legs upon landing, flight time and jump height calculations may be affected. - Participants must avoid arm-swinging during the test.
Isokinetic dynamometry	Isokinetic dynamometry assesses muscle strength and joint function. During the test, an athlete pushes against a dynamometer (a device measuring force) attached to the affected joint. The dynamometer provides resistance to maintain a set speed during the movement. Isokinetic testing is valuable for understanding force-length-velocity relationships in muscles.	- Isokinetic dynamometry provides quantitative data on muscle strength. - The test maintains a constant velocity, reducing injury risk. - It can predict shoulder injury risk and assess muscle function. - Isokinetic testing guides rehabilitation exercises and training programs.	- Requires specialized isokinetic machines and proper setup. - Only evaluates static strength, not dynamic muscle function. - Correct positioning and effort influence results. - Does not replicate real-world movements.
NoardBoard	The NordBord is a hamstring testing system. It assesses hamstring strength and the balance of strength between legs. The NordBord is widely used for assessing individuals and sporting teams.	- The NordBord is proven by dozens of research studies and has set the standard for hamstring strength assessments.	- Requires access to the NordBord system. - Focuses solely on hamstring strength and does not assess other muscle groups.

	When used alongside the app, it enables quick and accurate measurements.	- Setting up, testing, and reporting take under a minute. Real-time results allow for immediate feedback. - Provides quantitative data on hamstring strength. - Measures both eccentric and isometric hamstring strength.	

IMTP: Isometric mid-thigh pull; 1RM: One-repetition maximum; RFD: Rate of force development; CMJ: Countermovement jump, SJ: Squat jump; DJ = Drop jump; SSC: stretch-shortening cycle