Multi-Directional Speed in Youth Soccer Players: Programming Considerations and Practical Applications

Abstract

Multi-directional speed (MDS) can be defined as ‘the competency and capacity to accelerate, decelerate, change direction, and maintain speed in multiple directions and movements, within the context of sports-specific scenarios’. The components of MDS are linear speed, change of direction speed, curvilinear speed, contextual speed and agility. A MDS development framework is provided for the practitioner which considers the complexities of the growing athlete within a progressive sequence of skill learning and adaptation. Practical examples for each MDS component are provided and discussed within weekly microcycle examples that represent different stages of development for the youth athlete.

Key words: sprinting, change of direction, agility, training load, soccer, youth athletic development.

Introduction

Multi-directional speed (MDS) can be defined as ‘the competency and capacity to accelerate, decelerate, change direction, and maintain speed in multiple directions and movements, within the context of sports-specific scenarios’ (90). MDS comprises of linear speed, change of direction (COD) speed, curvilinear speed, contextual speed, and agility, which each have unique physiological, biomechanical and neuro-cognitive characteristics that can either be differentiated or harmonized to optimise training. The purpose of this article is to provide readers with an applied framework to utilise the concepts of MDS within a long-term athletic development (LTAD) program.

When structuring a training programme, it is important to note that the underpinning improvements in performance are a result of the chronic exposure to training stimuli (132); therefore, managing fatigue and optimising performance capabilities through the strategic manipulation of physiological stressors are imperative. Numerous strategic approaches have been proposed to maximise training adaptation in athletes; for example, linear, conjugate, concurrent, block, and concentrated models of periodisation (63). However, given the inherent structure of a soccer annual calendar (e.g., pre-season ~ 4- to 6-weeks vs in-season ~ 40-42-weeks) mean the abbreviated windows in which to develop physical qualities can present as a common barrier to what is considered 'best practise' for practitioners embedded within elite soccer clubs (145).

In contrast to their senior peers, youth soccer players may be afforded a better opportunity to optimise athletic preparation with a long-term vision in mind. Rather than winning being the primary focus, an emphasis should be placed on the development of better youth soccer players in line with the club's philosophy, while promoting their fitness, health, and wellbeing. Therefore, the use of periodization approaches which permit for the structure of a training programme in stages and cycles in accordance with the progressive overload principle will enable desired physiological changes to occur. With the correct balance of workload and recovery, MDS training strategies can be used to progressively prepare the youth soccer players for the speed demands of the senior game.

With that said, the authors acknowledge that constraints may be placed on the amount of gym-based activity their youth athletes can experience (i.e., low training age and/or limited resources). It should be noted, however, that strength is considered a fundamental quality to train in youth (79–81) and, given that the young soccer player will typically have a low training history, positive adaptations to an individual's strength characteristics can be made with simple methods that require limited equipment (56). Therefore, a "mixed-methods" training approach (53,132) within the frameworks of block periodization and phase potentiation may provide a viable long-term strategy for maximising the transfer of training and physical preparedness (31,32). Importantly, the integration of MDS training within these paradigms can work to complement the development of skill and physical qualities simultaneously. Demonstrating the importance of a holistic approach in MDS development, training must be configured in a way in which all phases of each MDS component are learned in sequential order, as to reinforce physical literacy and technical proficiency in movement. Speed performance in soccer is rarely linear, and as such, more investigations are warranted into how these approaches can work towards bringing about specific physiological adaptations that are complementary to the kinetic, kinematic, and spatiotemporal characteristics unique to a sequenced approach to MDS development (90). Until more is known in this regard, the aims of these next sections are to discuss a theoretical framework for the field-based development of MDS within the context of LTAD.

Multi-Directional Speed in a Long-Term Athletic Development Framework

Programming for the youth athlete requires careful consideration, due to the complex nature of growth and maturation, with which the timing and tempo of such processes are highly variable between each individual (84). The development of various sub-systems (i.e., skeletal, central nervous and cardio-respiratory), altering hormonal concentrations, alongside the changes to functional tissue (i.e., morphological, metabolic and mechanical) will bring about improvements in physical abilities, such as muscular strength, power, sprint speed, anaerobic and aerobic capacity, as an individual matures (5,7,114,116,144). Due to the non-linear development of such processes, certain authors have proposed models that are based on theoretical “windows of opportunity” in the training of targeted physical attributes, whereby youth athletes are more sensitive to training-induced adaptation at specific periods of development (8,144,151). These proposed models, such as the long-term athletic development (LTAD) model (8), have been widely adopted in youth athletic development practises, aiming to provide a progressive framework for coaches and practitioners on which to coach and develop their youth athletes within a multi-year training structure (8).

With respect to speed development, however, it has been shown that only weak to moderate relationships between changes in testosterone levels (51), growth rates in stature or body mass (20,150), and sprinting development exist during adolescence. Changes in leg length which correspond to growth have been suggested to explain improvements in sprint speed through increases in stride length (128), yet this cause and effect relationship remains unclear.

Morphological characteristics have been shown to differentiate sprinting performance in top-level sprinters, whereas leg length did not (75). Taken together, these results suggest that a host of factors, such as changes in muscle mass (144), muscle-tendon morphology (73) and neural mechanisms (83,104) can all influence sprinting development, which may be explained by a combination of growth, maturation, physical, and chronological factors (e.g., motor skill learning), and not merely 'sensitive periods' of development in relation to key time points with respect to biological age. As such, alternative frameworks have been proposed that demonstrate that all physical attributes are trainable during all phases of development (42,81,140), and it is perhaps, more specifically, the explicit training method itself that is most effective to develop a physical attribute during a certain phase of development (140).

What is well established, however, is that the ability to effectively apply large relative ground-reaction forces in the intended direction of travel is essential in MDS performance (26,39,74,91,149), of which should remain a key theme running through all stages of a LTAD programme. These training methods should be trained concurrently, but at different volumes, densities, and intensities, with respect to the individual's needs, which is the fundamental basis of periodization. Resultantly, it is now widely recognised that previous training experience should be a primary factor in the level of technical and physical requirements of a given training task, irrespective of age or maturity level (79). Thus, the proposed framework for the development of MDS uses 'training age' as a key modulator in the planning and progression of MDS training.

The authors propose a three-phase structure for developing MDS (Figure 1), where, from a motor skill learning perspective, pre-planned drills are required to learn correct techniques, with gradual progression in intensity (i.e., velocity and angle) and complexity (i.e. introduction to stimuli) as the athlete develops in movement competency and capacity (38,100). This phased structure aligns with the principles of the short-to-long (S2L) approach, which is a training methodology that has been adopted in elite sprinting (44,45), and extended in other sprint-related disciplines, as a means of harmonising the physiological adaptations derived from phased resistance training, sport training, and speed enhancement (i.e., Seamless Sequential Integration; SSI) (30). Briefly, the S2L approach is a speed development strategy based on the theoretical basis that athletes who can accelerate for greater distances will likely attain greater maximal velocities (119). The pioneer of this approach, Charlie Francis, also explains how technique is a pre-requisite and high skill levels need to be developed early in the pursuit of sprinting excellence (44). The model prescribes shorter sprints at the start of the training cycle that are progressively extended over time as physical and technical characteristics of the athlete matures (44,45).

Integrating this type of approach within the tenants of SSI has been suggested in relation to the acceleration capabilities of soccer players, where preliminary investigations into the distinct parameters associated with each sub-phase of acceleration, and their relationship with key strength-power characteristics, have been explored (11,12). Extrapolating these findings to the context of MDS, it is clear to see how these concepts can be conceptually applied. In a brief example, in theory, one may couple deceleration technique and 'tempo' / flywheel eccentric resistance training (134,135) as a method for developing a foundation of deceleration capabilities. The adaptations realised from this block of work, namely technical competency and eccentric strength, may then carry over to a subsequent training block in which the MDS emphasis may be deceleration capacity, where drills of greater approach velocities (increased distances) and COD angles (>90°) are utilised to intensify deceleration loading. As such, with an understanding of the key kinetic and kinematic characteristics within each individual component of MDS (90), practitioners can aim to train strength and speed concomitantly with the goals of harmonising a milieu of physiological and neurological adaptations to optimise physical preparedness and MDS performance (Figure 1).

What must be acknowledged, however, are the inherent concerns that coincide with the adolescent growth spurt in youth athletes. Young individuals are particularly susceptible to growth-related injuries around the ages of PHV (19,139), or when growth rates are high (65,71,89,139), which will have important implications for the implementation of MDS training.

The rapid gains seen during the adolescent growth spurt can result in neuromuscular control deficits (112), to which it has been suggested that previously attained movement patterns may need to be re-learned or modified (114). From a biomechanical perspective, the rapid growth of the whole-body and changes in limb length and mass will lead to increased moments of inertia around the joints (2,57), which may exacerbate injury risk, particularly if 'at risk' postures are demonstrated (e.g., knee valgus during cutting) (58,68,91). Therefore, an emphasis on sensorimotor function and re-addressing fundamental MDS technique principles is recommended for individuals experiencing rapid growth (Figure 1). Furthermore, the increases in sprint speed as an individual matures (i.e., increase in body size and mass) (112,120) indicates that the youth athlete will experience an increase in their whole-body momentum (i.e., ↑ mass x ↑ velocity = ↑ momentum) during sprinting, which will subsequently require greater braking impulse to reduce this momentum. Resultantly, during MDS movements, heightened musculoskeletal loading may manifest with which the rapidly growing athlete may be unaccustomed to. Preliminary investigations support this observation, where, in elite academy soccer players, the rate of performance increases in linear speed (e.g, 5, 10 and 20 m) corresponded with increases in maturity, whereas this rate of improvement was significantly reduced in the performance of a 180˚ COD test during the period of PHV (108). Thus, an emphasis on deceleration competency and capacity during this phase is highly recommended, 'you wouldn't drive a sports car without good quality brakes'. Although largely speculative, the inherent nature of this type of training (i.e., reduced exercise intensity due to a technical emphasis) may also be a means of reducing the overall training load (TL) within the week for individuals who may be sensitive to the intensive demands of training (139). The temporary vulnerability of bodily tissues, including musculotendinous junctions, ligament structures, growth cartilage and bone mineral density during this period (2,15,139,146,147) may reduce the loading capabilities of the young athlete, which needs to be carefully managed in order to reduce their risk of sustaining an injury.

Insert Figure 1 around here

It is within this holistic overview of the growing athlete that a decision can be made on the appropriate training methods to employ. For example, training methods that emphasize diversity and a variety of stimuli in pre-pubertal individuals will serve to maintain the interest of child athletes and develop multi-skill agility (103). The unique physiology of the less mature individual means that sprint-type activity requires less recovery time to perform subsequent bouts at high-intensity, due to reduced force-producing capabilities of immature children (98,117). The self-regulatory nature of game-based training will serve to keep the child athlete active and engaged, while still developing MDS qualities. Alternatively, more physically demanding training methods (e.g., increased volumes and intensities) that harness the late-pubertal individual's heightened androgenic responsiveness, who will typically possess a greater training age and TL tolerance, may allow for an emphasis to be placed on building movement capacity, developing specialised movement capabilities, and providing supplementary resistance-based strategies that develop explosive strength qualities (49,50,80,81,115,151).

This decision process should operate on a fluid continuum, where different densities and intensities are targeted depending on the individual (Figure 1). It should be noted that each phase should still be incorporated throughout the various stages of a MDS development programme; however, the density of each phase will vary depending on the individual's training age, chronic training load, maturation status, rate of growth, technical competency, and physical strengths and weaknesses (Figure 1). Anecdotally speaking, the cultural and philosophical values of the soccer club can play a huge role in the implementation of any athletic development model the practitioner chooses to utilise. The development of a MDS model should be by no means a rigid structure and aim to harmonise the club's core principles with the scientific principles of MDS. This approach will work to optimally facilitate the integration of the club's technical and tactical principles within a MDS development framework (90).

Programming Considerations

To date, recommendations for the appropriate frequencies, volumes and distances of MDS training are limited for the youth population, with the relationships between the TL, athletic performance and injury risk being unclear (46). It has, thus far, been difficult to determine how to best structure sprint training in youth (121). General recommendations for sprint training suggest that youth athletes should perform up to 2 sprinting sessions per week, with up to 16 sprints within distances of 10 to 30 m, accumulating total distances between 240 to 480 m each session (94,122). Efforts of sprints should be interspersed with at least 90 s of rest, or a work-to-rest ratio of 1:25, to allow for full recovery (94), with the aim of sessions being to perform high-quality, technically sound work, while maintaining maximal exercise intensities.

These recommendations, however, are generic in nature, and specific guidelines for the different components of MDS training (i.e., acceleration, deceleration, COD, curvilinear sprinting, and maximum velocity) need to be developed for the youth athlete and are recommended areas for future research. As mentioned previously (90), MDS manoeuvres display different kinetic, kinematic and spatiotemporal characteristics, in which the performance of such actions will have implications for the physiological and biomechanical load-adaptation pathways, which have different rates of response (141). This may have consequences for the planning and periodization of specific components within the MDS continuum, both at the micro- and meso-level, when determining the appropriate dosage of MDS components within training cycles (Figure 2). For example, in late-adolescent soccer players, 2-weekly COD speed and technique training sessions within shorter distances (i.e., ≤ 20 m) have seen athletes complete up to 54 COD maneuvers (e.g. 4-25 decelerations; 20-38 COD actions) and total distances between 230 and 425 m each session, all within relative intensities ranging between 50 to 100 percent of perceived speeds (34). Conversely, dosages concerning maximum velocity sprinting, typically performed over greater distances (i.e., ≥ 30 m), may require markedly smaller overall volumes. Research from elite Gaelic footballers suggests that, per session, 6 to 10 maximum sprint speed (MSS) exposures, attaining at least 95% of MSS, and accumulating total sprinting distances between 60 to 90 m, was necessary to reduce injury risk and prepare athletes for competition (88). Pertinently, when performing higher volumes of MSS distance (e.g., 120 to 150 m), players with higher chronic TLs presented a markedly lower injury risk (Odds Ratio; OR = 0.26) in comparison to their teammates with lower chronic TLs (OR = 3.12) (88). Further investigations are certainly warranted to determine the appropriate TL and dosages for field-based MDS training in youth soccer players.

Ultimately, when prescribing MDS training, the practitioner should be aware of the numerous considerations that have been discussed above. It should be recognised that youth soccer players are engaged in other forms of physical activity (i.e., training and match-play), which can expose them to high volumes of high-speed running distance, sprinting distance, acceleration and deceleration actions within their skill-based work. Moreover, the youth athlete may be involved in additional sporting activities, physical education classes in school, or even represent other soccer clubs at regional or national levels. This should reflect in the relative dosage of MDS training within specific time frames (Figure 1). It is also appreciated that, due to the limited resources available at the youth soccer level, access to advanced monitoring technologies, such as global-positioning systems (GPS), may be difficult. Resultantly, we advise and encourage practitioners to be initially conservative with the volumes and movement intensities they expose their youth athletes to, with an emphasis placed on quality and fun, rather than quantity, and monitor how their athletes respond to training through continual communication, alongside the utility of readily-available methods, such as subjective load and wellness and the monitoring of injuries and pain (97,125,136,137). As previously stated, a better understanding of the optimal dosages for MDS development is required in both adult and youth populations. With that said, we recommended a training approach where total distances (e.g., 230-480 m), MSS distance (e.g., 60-90 m), COD's (e.g., 20-40) and decelerations (e.g., 2-40), are performed within a range of distances depending on the MDS focus (e.g., 2.5 – 60 m). Practitioners should also limit week to week changes, or progressive increases, within 10% for the aforementioned variables (16,33,113,131). Anecdotally, we have adopted this approach in elite and sub-elite youth soccer populations and found this method to be successful and can be integrated into extended warm-ups (examples provided in following sections), prior to skills-based sessions for approximately 15-30 minutes.

Training Methods

With an understanding of the theoretical underpinnings of MDS, combined with an appreciation for the unique considerations for the growing adolescent athlete, practitioners are better able to identify exactly what physiological or biomechanical mechanisms they are aiming to appropriately overload at specific time points within a programme. Ultimately, in the applied world, practitioners are challenged with the task of identifying the most suitable training methods to attain the desired outcomes from their athletes, of which can be highly dependent on the context in which it is applied.

Although far less extensive, findings from research have demonstrated the effectiveness of a variety of training interventions (e.g., traditional sprint training, resisted sprint training, plyometric training, resistance training, or combined training) on components of MDS speed (6,47,69,102,121). A variety of methods for developing force production capabilities (i.e., resistance training, plyometrics, resisted sprinting) are recommended to work in concert alongside field-based training methods to reinforce MDS performance and to elicit positive tissue adaptations (i.e., bone, ligament, tendon and muscle). Although they will be briefly discussed in this section, readers are directed to the following texts for more descriptive reading on these complementary methods (53,59,133,138). The following sections will discuss how the concepts proposed by the authors can be used for developing MDS qualities in youth soccer players. The overarching philosophy for MDS development in youth soccer players should be to expose their athletes to an expansive range of diverse movement skills, developing robust and effective multi-directional athletes, who have the competency to accelerate, decelerate, and change direction rapidly and effectively from both limbs. As such, the aims of this section are to provide some practical examples of how training methods along the MDS continuum can be implemented in a soccer setting.

Linear Speed

As previously discussed, an athlete's ability to accelerate is governed by the amount of horizontal force that is effectively applied to the ground (61,74,95,149). An effective horizontal transmission of these forces over increasingly abbreviated GCT during acceleration has been termed mechanical effectiveness (124). It is recommended that the development of mechanical effectiveness work in compliment to a gym-based conditioning programme, which can be achieved through targeted resistance training of the mechanical qualities (i.e., force, velocity and power) that underpin the kinetics specific to each sub-phase of acceleration (Figure 2.A). Researchers who have evaluated the effects of sprint-specific training methods on linear sprint performance (i.e., free, assisted- and resisted-sprinting) have shown them to demonstrate favourable adaptations to specific aspects of the force-velocity profile in athletes (21–24,28,59,111). For example, 'heavy' sled towing loads (e.g., > 75% decrement in velocity; Vdec) may target specific 'force' aspects through training strength-speed qualities (21,23,28,59,111), which may correspond to earlier sprinting phases (e.g., early- and mid-acceleration; Figure 2.A). Alternatively, 'lighter' loads (e.g., <25% Vdec), free or assisted-sprinting (21,23,28,59,111) may of benefit to later sprint phases (e.g., late-acceleration, 'transition' or maximum velocity; Figure 2). As previously discussed, with an understanding of the kinetic, kinematic and spatiotemporal factors that govern specific elements of the MDS continuum (90), increases in sprinting performance may be achieved through manipulation of targeted loads within a given zone of training. Readers are directed to the following reviews for a more comprehensive overview of resisted-sprinting training methods (4,22,24,28,111).

Another consideration is that of the starting position for acceleration, as in soccer, players will initiate movement from a variety of positions (i.e., crouched start, athletic stance, walking, jogging, or soccer-specific actions) during match-play. Exposing the athlete to a variety of different sprint-start positions (Figure 2.B) will thus serve as a means to develop an athletes movement library by exposing them to a range of postures which can influence the kinetic and kinematic outcomes of the first few steps of acceleration (96,130). As sprinting distances increase, practitioners should be cognisant of the characteristics that demarcate a transition to near maximum velocities. These are unique to each athletic population; for example, in rugby union athletes, 96% of maximum velocity was achieved by every athlete at the 21-metre mark (9). The stimulus provided to the athlete for attaining >95% of peak speed is of great benefit from both performance and injury perspectives (88,92), yet these intensities are also highly taxing on the central nervous system and require conscious management in dosage. Practitioners should aim to develop their own population-specific sprint profiles for their athletes, which will ensure the sub-phases of acceleration are accurately classified and ensure that larger sprinting distances are dosed appropriately.

Further to this point, a variety of “ins-and-outs” drills can be a useful strategy in the management of sprinting distances to the same effect (Figure 2.C). Although the science less clear in this regard, theoretically, these drills may allow for the manipulation of movement speeds within a drill associated with maximal effort sprinting, while still re-enforcing sprinting mechanics. Speculatively speaking, these types of drills could be used with players going through periods of accelerated growth as a means of reinforcing sprinting technique and locomotive economy within reduced movement speeds. Furthermore, varying the movement intensity within a pre-determined distance enables players to initiate sprints from a variety of locomotive profiles (i.e., walking, jogging and running), which more likely replicates the stochastic nature of soccer.

Insert Figure 2.A, 2.B and 2.C around here

Change of Direction Speed

COD speed can be considered the mechanical basis for effective agility (38,40,100,129). Similar to the principles of linear speed, COD speed is determined by the technical ability to effectively apply force in the intended direction of travel (36,39,67,91). It is important to develop the athlete's technical competency using a controlled and progressive approach, which can reinforce desirable movement mechanics through shallower angles before movement intensities are increased (Figure 3.A). These initial drills enables the coaching of different COD actions, such as side-steps, cross-over cuts (XOC), split steps, pivots, as well as initiation and transitional maneuvrability movements, with low movement intensities that emphasize technique and control. Readers are referred to the following texts for a detailed and prescriptive guide on appropriate technical coaching guidelines for the underpinning qualities of COD speed (35,38,40,100). As movement quality is developed, the volume of COD maneuvers can increase by including more actions within the same drill (increased task complexity) (Figure 3.B). This will allow for the movement capacity of the athlete to be developed while embedding the desired movement mechanics of each action. Finally, introducing sports-specific, multi-directional actions within the same exercise will allow for the realisation of COD speed to be achieved, allowing for the individualization of movements which can be specific to playing positions or tactical scenarios (Figure 3.C). By isolating these sports-specific movements within MDS training, practitioners can begin to emphasize technical efficiency, while overloading the specific force demands of the actions by completing them with maximal intent.

Insert Figure 3.A, 3.B and 3.C around here

Deceleration

Although deceleration as a quality can be encompassed within COD speed, it is of the author's beliefs that a standalone section is warranted. The importance of deceleration competency and capacity for the rapidly growing athlete cannot be understated; the preparatory steps prior to a COD foot plant are fundamental for effective COD speed and have vital implications for both COD performance and injury risk (40,54,55,66,67). Deceleration mechanics should be firstly developed through an emphasis on technique, where the athlete is required to perform a range of deceleration maneuvers in different positions and at different angles of approach (Figure 4.A). Once technical competency has been advanced, movement intensities can begin to increase through exposing the athlete to greater approach velocities, making sure to continually embed desirable deceleration mechanics (Figure 4.B). Given the inherent increase in approach velocity that will occur with greater distances, deceleration 'zones' can also be increased to accommodate for this increased movement intensity; equally, dependent on the athlete's physical capacity, these areas can be manipulated to facilitate sharper deceleration intensities. Once the fundamental mechanics have been developed and deceleration competency and capacity is improved, the inclusion of game-based elements will diversify some of the more repetitive exercises associated with the previous examples, adding a fun and competitive element for the youth athlete, which can also facilitate an increased effort and movement intensity (Figure 4.C). Moreover, exercises such as these often have the presence of external stimuli that are generic (i.e., visual or auditory) and sports-specific (i.e., partner reaction or evasion), which are also methods for progression to increase specificity and greater overload.

Insert Figure 4.A, 4.B and 4.C around here

Curvilinear Speed

Much less is known about curvilinear speed; however, the mechanics have much closer resemblance to linear sprinting than that of COD (38). Importantly, it has been shown that ~85% of maximum velocity actions in match-play do in fact have some degree of curvature (25), and so developing the ability to maintain high velocities during curved sprints are vital. Technical guidelines for developing curvilinear speed are limited; however, in theory, a similar framework can be applied to that of COD speed and can be utilized supplementary to COD training. Therefore, technical competency should be emphasized through shallower curves before movement intensities are progressively increased with curves of greater angles and radii (Figure 5.A); these can be developed concomitantly with shallow forms of COD actions (i.e., < 45˚), where braking is limited, and velocity maintenance is a key focus (see Figure 3.A and 3.C). As curvilinear movement mechanics improve, the volume of curved maneuvers can increase by including more actions within the same drill (Figure 5.B). This will develop the movement capacity of the athlete by increasing the density of curved maneuvers performed in an exercise. Practitioners can also aim to increase movement intensities through an increase in the distance of the curved sprint and expose their athletes to higher velocities, which may be combined with linear maximum velocity work when high-speeds are the focus.

Insert Figure 5.A, 5.B and 5.C around here

Agility

The qualities discussed above (i.e., linear speed, COD, deceleration, curvilinear speed) can be considered the mechanical basis for development of MDS; however, the training of these qualities in true isolation should be considered as pre-planned tasks. In sports, such as soccer, the ability for athletes to use information from the environment to support actions is predicated on an accurate and efficient relationship between perceptual-cognitive factors and motor processes (123). Therefore, agility training requires a perceptual and decision-making process in response to a stimulus, of which the subsequent outcome will likely fall into the category of one of the aforementioned actions (129).

The most basic form of these types of exercises may be through the incorporation of an external stimulus (e.g., player, signal, or command) within a pre-determined task (Figure 6.A). This allows for the control of approach velocity and angle of the subsequent MDS action, while introducing perceptual and decision-making element through engaging the athlete with an external condition. Continued evaluation of technique is advised when introducing these exercises, as the reduced time to make preparatory whole-body postural adjustments during unanticipated maneuvers may potentially contribute to poor frontal and transverse kinetic and kinematics, such as increased lateral trunk flexion and unwanted positioning of the centre of mass, all of which are associated with potentially hazardous knee joint loading (13,14,39,68,91). The heightened knee joint loading during unanticipated actions can be attributed to increased task complexity and temporal constraints imposed on the central nervous system which controls movement, and thus, contributing to the disproportionately greater external knee joint moments, which are in contrast to the levels of muscle activation required to offset the adoption of higher-risk postures (13,14).

The progression of agility training should challenge the athletes to respond with varied movement solutions by providing conditions that are more open in nature (Figure 6.B).

Exercises may still be designed with the intention of exploiting desired MDS actions that wish to be emphasized, but the unpredictable nature of these open drills will consequently forsake some degree of control. These types of unpredictable exercises expose players to opposed evasion scenarios which most closely resemble sporting movement, where the athletes will need to synchronise their perception-action coupling abilities through truly challenging perceptual and decision-making processes (i.e., visual scanning, knowledge of situations, pattern recognition and anticipation) in response to sports-specific stimuli (101,110,152). Importantly, in sport, athletes do not react to flashing lights, arrows or colored cones; instead, they scan and process visual and kinematic cues regarding the environment, sport, and other athletes when performing MDS actions (110,152). Although a popular method, and arguably warranted in instances when diversifying training to improve player motivation, the use of an unanticipated stimulus in the form of the abovementioned has been criticised because they are not truly sport-specific stimuli (101,110,152). Furthermore, researchers have shown these types of ‘reactive agility’ exercises (i.e., flashing lights or arrows) do not differentiate skilful performers (152–154), and, in fact, may even be a more complex and hazardous task compared to reacting to 2D video footage (76).

Finally, the inclusion of game-based agility exercises can be an excellent tool for providing variety and enjoyment in a programme and are particularly effective for re-enforcing movements with an element of fun when working with younger players (Figure 6.C). Due to these games often being team-oriented, they can also be a useful method for embedding technical and tactical outcomes as a secondary objective, which can be developed alongside support from the technical coaching staff. These exercises will typically provide the highest cognitive load because of their more chaotic nature (i.e., objectives, rules, and greater player numbers). Due to the typically greater durations of game-based exercises, practitioners should be aware that the underlying physiological emphasis may shift towards a more anaerobic or aerobic outcome, and so work to rest ratios need to be considered depending on the overarching theme of the session.

Insert Figure 6.A, 6.B and 6.C around here

Contextual Speed

It is important to understand that any movement that presents itself during match-play is the result of a perception-action coupling in response to a specific scenario that occurs within the game. Therefore, MDS will always be applied to a specific context within match-play, and will vary depending on an individual's playing position and tactical role. Therefore, there should be continual communication with the technical staff in relation to desired themes of work through embedding the club's game model (90), as well as an individual's positional characteristics, which will require a special reference to their unique movement patterns, pitch location, technical skills, tactical actions and combination play (1,64). This will allow for MDS speed qualities to be realised within the true context of soccer performance (Table 1).

Various MDS actions can be isolated and overloaded through targeted exercises that are specific to the positional and tactical requirements of that individual. The principles of progression within the MDS development framework (Figure 1) develop contextual speed in the same way, with the initial use of closed, pre-planned drills that allow the competency and capacity of contextual movement to be developed, followed by the introduction of external stimuli (e.g., opponent) in more intense open drills (Figure 7.A). Drills which incorporate a technical focus can then be designed which replicate the same focus within a soccer-specific scenario (Figure 7.B), with which the constraints (e.g., no. of players, pitch location or objectives) can be manipulated accordingly for the desired outcomes. The inclusion of a technical element within a MDS session does come with an inherent caveat, namely, that there presents a risk of 'diluting' the training effects of high-quality MDS work. With any additional layer of complexity that is apparent when including a technical focus, the risk of a poorly executed technical action may also result in a reduction in movement quality in the MDS maneuvers that are being focused on. Furthermore, to truly replicate the demands of individual playing positions, the inherent differences in work to rest ratios may shift the emphasis towards a more anaerobic or aerobic conditioning-based drill. Therefore, if MDS training were to precede a main technical session (i.e., warm-up), it is recommended that these types of 'integrated' drills be introduced towards the end of the session to allow a transition towards technical training, without compromising high-quality MDS work.

Insert Table 1 here

Insert Figure 7.A, 7.B and 7.C around here

Implementation of the Training Plan

It should be re-iterated that MDS training should be considered within a holistic athletic training programme, which encompasses other training components that are complementary to MDS development. It is, therefore, suggested that the planning and prescription of training to develop MDS is considered in the broader context of the youth soccer player's training environment, which considers the intricacies of TL, growth and maturation, training experience, as well as other factors that are at play within a certain period of a young soccer player's developmental journey (Figure 1). It is of the author's beliefs that the assessment of growth and maturation should be a key driver in determining the content of MDS training delivered to the youth athlete (29,79,81,82,84,87). As mentioned previously, there is much variation in the timing and tempo of an individual's growth, maturation and development (84–86), particularly within the adolescent years (i.e., 11 to 14 years) (87), which can lead to large disparities in performance across a range of athletic tasks between individuals of the same chronological age (17,84,108,112).

Practical, indirect assessments of skeletal maturity are now popular in the applied world (72,87,93). The approach adopted by the authors is the percentage of predicted adult height (%PAH) method, which provides an estimated index of maturity status and timing (72,109). With this information, practitioners can decide to more appropriately categorise individuals into athletic training groups based on maturity status, as opposed to chronological age groups; for example, <90% PAH, >90% to <95% PAH, and >95% may equate to individuals who are early- to pre-pubertal, mid-pubertal, and late- to post-pubertal, respectively (29). Notably, PHV may occur between 88 and 96% of PAH, reaching its peak between approximately 90 and 92% (109), which may have implications for training; however, practitioners are advised to collect and develop their own growth and maturation data that is population-specific, wherever possible.

The structure of a weekly training plan may be highly variable and the decisions on when and where to deliver training can be dependent on the unique situations of different clubs, as well as the governing bodies that arrange fixtures. Quantitative and qualitative analysis into the movement profiles of youth soccer match play, and how this progresses within an academy, is important for optimising developmentally appropriate training prescription (107,126). Certainly, more investigations are warranted in this regard to elucidate the match activity profiles that are specific to the age, maturity- and ability-level of the groups in question (17,48,107). Combining this information with growth and maturation data will allow practitioners to reverse-engineer their weekly training programmes to provide the optimal overload to key MDS characteristics that are more specific to an individual's requirements. An example of how a MDS programme can be implemented on the micro-level, within biologically-banded weekly training structures that represent post-, circa-, and pre-PHV groups are provided (Table 2, 3 and 4, respectively). In these examples, the alignment of training days between chronological age groups may be preferential to facilitate the fluid movement of individuals of different ages within biologically driven athletic training groups.

Of note, individuals classified in the post-PHV training example, who will typically have greater physical capabilities, training experience and chronic workloads, may be exposed to a higher TLs throughout the week (e.g., weekly load = 2430 arbitrary units; AU), with a greater emphasis on developing physical capacity in highly specific movement scenarios (Table 2). Furthermore, at these later stages of development, players need to become increasingly more prepared for the demands of the senior game, and so there is a much greater emphasis on performance in competition. Thus, two days of 'acquisition', where MDS demands are high, are strategically placed at the early stages of the week (e.g., match day -4 and -3), followed by three-day pre-match tapering strategy where lower intensity technical, tactical, and individual focuses can be emphasized, which will assist in the gradual 'unloading' of players and reducing the accumulative fatigue response that serves to increase player readiness for the match (70,106,145).

Conversely, circa-PHV players, or individuals with heightened growth rates, may require a reduction in training volume (e.g., 1950 AU) to control for pain and reduce the risk of sustaining an overuse injury (65,71,89,97,139) (Table 3). Notably, this reduction in TL should come through a reduction in session duration, and not forsake exercise intensity, where appropriate, to allow for high-quality MDS training to still be performed. The structuring of MDS training may be managed in a way that allows more days between from 'high' TL days to accommodate for the rapidly growing athlete's need to recover, also allowing the next high-intensity MDS session to be performed under lower residual fatigue and with higher intensity (70). Importantly, individuals going through rapid growth will likely experience a rapid enhancement in physical performance capabilities that will need to be carefully managed to ensure all MDS components are underpinned by movement quality, which will better prepare these individuals for the increasing demands of match play and reduce the risk of injury.

Finally, due to the unique physiology of pre-PHV players, less of an emphasis on weekly TL periodization is necessary due to their reduced physical capabilities. A key focus for this maturity group, however, will be to offset the negative consequences of early-specialisation, and allow individuals to sample a range of different sports and movements within MDS training (Table 4). More attention may need to be given to groups who are approaching phases of rapid growth to establish 'baseline' data (e.g., more frequent monitoring of growth rates, establishing baseline movement quality (37) and match/training data) to allow for comparison, where possible. The use of subjective ratings of perceived exertion (RPE) (43,62) can provide information regarding the internal response of imposed external loads and determine whether an individual is coping with the training demands. More research into the validity and reliability of this method in youth soccer players, however, is needed, as mixed findings have currently been reported in this population (52,118,127). The use of this tool in 'under-resourced' organizations would certainly be of value, as RPE may provide a simple, non-invasive means of assessing 'global' training load (e.g., both physical and psychological stress) during intermittent activities, such as soccer (52).

Insert Figure 8 around here

Although individualization of training is often touted as paramount for the successful development of athletes, it is acknowledged that team-sports often require the majority of training to be undertaken in group-based activities. In certain situations, however, supplementary training sessions with a more individual focus (e.g., position-specific themes) may be included within a holistic programme that accommodates for athletes that need to develop qualities that are more specific to their individual needs. To this end, physical assessments can be utilised to evaluate an individual's underpinning strength characteristics, movement quality, and asymmetries to identify strengths and weaknesses of an athlete. The use of individual growth rates alongside this approach may further individualize the delivery of a program, which can inform training approaches. For instance, as players can often experience spikes in growth rates throughout various periods of their adolescent journey, and not just 'circa-PHV', a player may sporadically go through periods of reduced co-ordination, display exacerbated asymmetries, or present a general reduction in perceived wellbeing and readiness to train, which may need to be considered in the tailoring of a program.

Insert Table 2, 3 and 4 around here

Practical Applications and Future Directions for Monitoring Multi-Directional Speed

As mentioned previously, particularly at the youth soccer level, access to advanced technologies and analytical methods may not be readily available to clubs with limited resources. However, recent trends have indicated that the ability to evaluate TLs through the utility of these methods, such as GPS and various micro-technologies, have become more commonplace (3) and will continue to become more accessible (18). Surveys into current soccer practises (3) reveal that clubs incorporate a variety of metrics to evaluate TL in their athletes (e.g, total distances, speed-time, relative speed intensities, accelerometry, metabolic power), all of which can provide valuable insights into the monitoring of MDS actions. A selection of these kinematic measures (e.g., total distance, high-intensity distance) are utilised as a means of managing the physiological load-adaptation pathways, which are typically characterised by metabolic and cardio-respiratory adaptations. From a biomechanical loading perspective, accelerometry-based variables can be used to provide an overview of summative body-impacts that a player is exposed to during a session (e.g., PlayerLoad (10)), which are examples of 'whole-body' load measures that aim to approximate the external forces the body is exposed to and reflect the loading demands placed on the musculoskeletal system (99,142).

Although practical for field-based purposes, 'whole-body' estimates of musculoskeletal load fail to account for the highly variable nature of biomechanical loading that occurs at the structural level (e.g., joints, segments, limbs) during different COD actions, with laboratory-based investigations indicating this can be highly task-dependent (35,38,39,91,143). For example, if an athlete were to perform a MDS session where the focus was to be on deceleration capabilities, utilising a biomechanically-focused metric (e.g., total decelerations) to evaluate that session may under- or over-estimate the training demands placed on the athlete's joints, muscles and tendons depending on the angle and velocity the athlete performed each of these maneuvers (35). In addition, as mentioned previously, the importance of practical methods for monitoring these training demands through an evaluation of the individual's internal response is essential. Therefore, being able to differentiate between the physiological and biomechanical internal responses to various external TLs may further assist in developing specific dose-response relationships in soccer. For example, using differential-RPE, an individual may be specifically asked to rate their level of 'breathlessness' and 'leg muscle exertion' during a session or task (148), or evaluate their rating of 'muscle soreness' and 'fatigue' in the days following a session through a wellness questionnaire (60,137), which may separate an individual's perception of physiological and biomechanical load (141). As mentioned previously, more research is warranted to validate these novel methods, particularly in their applicability for use with youth players.

Consequently, the practitioner needs to be aware that the currently available measures for evaluating player activity levels on the field can be the product of highly varied demands at the structural and tissue level, which can have implications for evaluating the biomechanical adaptations to training and injury risk (142). This is important, as being able to differentiate between characteristic loading patterns, and how load-adaptation pathways are affected as a consequence, may allow for the periodization of long-term training programs to be optimized through the appropriate sequencing of physiological and biomechanical TLs (141). For example, an extended time-course (e.g., 6-8 weeks) for adaptation has been reported to occur between the cessation of eccentrically focused training and the manifestation of adaptations, characterised by improved outcomes in strength (27) and power (77). As such, a hypothetical example of how MDS may be sequenced in this regard using metrics commonly tracked with GPS systems is provided in 'Figure 8'.

Certainly, more investigations are warranted to uncover the optimal dose-response relationships between the various components of MDS and how the young athlete responds to the training of these components within different phases of growth and maturation. This will provide more insight into whether a hierarchy of MDS training requirements is appropriate at different phases of development. Given the underlying mechanism of an overuse injury, that is, potentially being a result of excessive loading of repetitive movement patterns (41,78), an understanding of the structure-specific mechanical loading a young adolescent soccer player is exposed to as a consequence of pathological movement may allow for modifications to be made to the training programme in order to mitigate injury risk. Additionally, how the components of MDS are developed within various learning and skill acquisition models needs further evaluation over the long-term, as alternative non-linear approaches that are more aligned to ecological dynamics rationale have been suggested in the design of effective skill learning environments (105).

Conclusion

This review has focused on how the scientific principles that underpin MDS can be applied within a LTAD program in youth soccer players. A theoretical framework has been proposed for the periodization, sequencing, and structuring of MDS, along with example exercises for each component of MDS. This development framework is underpinned by the interaction between training age, growth and maturation, and TL, which will ultimately dictate the MDS foci for an individual athlete. Young soccer players can and should be exposed to all aspects of the MDS continuum, but at different volumes, intensities, and densities, where appropriate.

At the micro-level, we provide in-season weekly training examples for pre- circa-, and post-PHV athletes, which aims to accommodates for the unique training considerations that are required at different stages of maturity and with increased rates of growth. How the long-term management of such training strategies at the meso-level work to reduce fatigue, injury risk, and optimise performance capabilities, is currently unknown, and very limited data exist for youth athletic populations; however, a proposed mesocycle, which considers the separate nature of physiological and biomechanical load-adaptation pathways, has been provided for consideration. Novel methodologies that specifically evaluate the varied demands of different MDS maneuvers, and how these interact with growth, maturation and development will perhaps shed more light on much needed answers to these questions and allow for more informed decisions to be made on individualized training prescription. With that said, irrespective of any proposed framework, the success of a program will rely on the fluid communication of information and ideas between key stakeholders, and how well the program accommodates the individual.

References

1. Ade, J, Fitzpatrick, J, and Bradley, PS. High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions: Information for position-specific training drills. *J Sports Sci* 34: 2205–2214, 2016.

2. Adirim, TA and Cheng, TL. Overview of injuries in the young athlete. *Sport Med* 33: 75–81, 2003.

3. Akenhead, R and Nassis, GP. Training load and player monitoring in high-level football: Current practice and perceptions. *Int J Sports Physiol Perform* 11: 587–593, 2016.

4. Alcaraz, PE, Carlos-Vivas, J, Oponjuru, BO, and Martínez-Rodríguez, A. The effectiveness of resisted sled training (RST) for sprint performance: A systematic review and meta-analysis. *Sport Med* 48: 2143–2165, 2018.

5. Armstrong, N, Barker, AR, and McManus, AM. Muscle metabolism changes with age and maturation: How do they relate to youth sport performance? *Br J Sports Med* 49: 860–864, 2015.

6. Asadi, A, Arazi, H, Young, WB, and De Villarreal, ES. The effects of plyometric training on change-of-direction ability: A meta-analysis. *Int J Sports Physiol Perform* 11: 565–573, 2016.

7. Bailey, R, Collins, D, Ford, P, MacNamara, A, Toms, M, and Pearce, G. Participant development in sport: An academic review. *Sport Coach UK* 4: 1–134, 2010.

8. Balyi, I and Hamilton, A. Long term athlete development: Trainability in childhood and adolescence. *Olympic Coach* 16: 4–9, 2004.

9. Barr, MJ, Sheppard, JM, and Newton, RU. Sprinting kinematics of elite rugby players. *J Aust Strength Cond* 21: 14–20, 2013.

10. Barrett, S, Midgley, A, and Lovell, R. PlayerLoad™: Reliability, convergent validity, and influence of unit position during treadmill running. *Int J Sports Physiol Perform* 9: 945–952, 2014.

11. Bellon, CR. The relationship between strength, power, and sprint acceleration in division 1 men’s soccer players. East Tennesse State University, 2016.

12. Bellon, CR, Deweese, BH, Sato, K, Clark, KP, and Stone, MH. Defining the early, mid, and late subsections of sprint acceleration in division 1 men’s soccer players. *J Strength Cond Res* 33: 1001–1006, 2019.

13. Besier, TF, Lloyd, DG, Ackland, TR, and Cochrane, JL. Anticipatory effects on knee joint loading during running and cutting maneuvers. *Med Sci Sports Exerc* 33: 1176–1181, 2001.

14. Besier, TF, Lloyd, DG, Cochrane, JL, and Ackland, TR. External loading of the knee joint during running and cutting maneuvers. *Med Sci Sports Exerc* 33: 1168–1175, 2001.

15. Blimkie, CJR, Lefevre, J, Beunen, GP, Renson, R, Dequeker, J, and Van Damme, P. Fractures, physical activity, and growth velocity in adolescent belgian boys. *Med Sci Sports Exerc* 25: 801–808, 1993.

16. Brenner, JS, Small, EW, Bernhardt, DT, Congeni, JA, Gomez, JE, Gregory, AJM, et

al. Overuse injuries, overtraining, and burnout in child and adolescent athletes. *Pediatrics* 119: 1242–1245, 2007.

17. Buchheit, M and Mendez-Villanueva, A. Effects of age, maturity and body dimensions on match running performance in highly trained under-15 soccer players. *J Sports Sci* 32: 1271–1278, 2014.

18. Buchheit, M and Simpson, BM. Player-tracking technology: Half-full or half-empty glass? *Int J Sports Physiol Perform* 12: S2-35, 2017.

19. Bult, HJ, Barendrecht, M, and Tak, IJR. Injury risk and injury burden are related to age group and peak height velocity among talented male youth soccer players. *Orthop J Sport Med* 6: 2325967118811042, 2018.

20. Butterfield, SA, Lehnhard, R, Lee, J, and Coladarci, T. Growth rates in running speed and vertical jumping by boys and girls ages 11-13. *Percept Mot Skills* 99: 225–234, 2004.

21. Cahill, MJ, Oliver, JL, Cronin, JB, Clark, K, Cross, MR, Lloyd, RS, et al. Influence of resisted sled-pull training on the sprint force-velocity profile of male high-school athletes. *J strength Cond Res* 34: 2751–2759, 2020.

22. Cahill, MJ, Oliver, JL, Cronin, JB, Clark, KP, Cross, MR, and Lloyd, RS. Sled-pull load–velocity profiling and implications for sprint training prescription in young male athletes. *Sports* 7: 119, 2019.

23. Cahill, MJ, Oliver, JL, Cronin, JB, Clark, KP, Cross, MR, and Lloyd, RS. Influence of resisted sled-push training on the sprint force-velocity profile of male high school athletes. *Scand J Med Sci Sport* 30: 1–8, 2020.

24. Cahill, MJ, Oliver, JL, Cronin, JB, Clark, KP, Cross, MR, and Lloyd, RS. Sled-push load-velocity profiling and implications for sprint training prescription in young athletes. *J Strength Cond Res* 34: 2751–2759, 2020.

25. Caldbeck, P. Contextual Sprinting in Football. Liverpool John Moores University, 2019.

26. Clark, KP and Weyand, PG. Are running speeds maximized with simple-spring stance mechanics? *J Appl Physiol* 117: 604–615, 2014.

27. Coratella, G and Schena, F. Eccentric resistance training increases and retains maximal strength, muscle endurance, and hypertrophy in trained men. *Appl Physiol Nutr Metab* , 2016.

28. Cross, MR, Lahti, J, Brown, SR, Chedati, M, Jimenez-Reyes, P, Samozino, P, et al. Training at maximal power in resisted sprinting: Optimal load determination methodology and pilot results in team sport athletes. *PLoS One* 13: e0195477, 2018.

29. Cumming, SP, Lloyd, RS, Oliver, JL, Eisenmann, JC, and Malina, RM. Bio-banding in sport: Applications to competition, talent identification, and strength and conditioning of youth athletes. *Strength Cond J* 39: 34–47, 2017.

30. DeWeese, B, Sams, M, and Serrano, A. Sliding toward Sochi—part 1: a review of programming tactics used during the 2010–2014 quadrennial. *NSCA Coach* 1: 30–42, 2014.

31. DeWeese, BH, Hornsby, G, Stone, M, and Stone, MH. The training process: Planning for strength-power training in track and field. Part 1: Theoretical aspects. *J Sport Heal*

Sci 4: 308–317, 2015.

32. DeWeese, BH, Hornsby, G, Stone, M, and Stone, MH. The training process: Planning for strength-power training in track and field. Part 2: Practical and applied aspects. *J Sport Heal Sci* 4: 318–324, 2015.

33. DiFiori, JP, Benjamin, HJ, Brenner, JS, Gregory, A, Jayanthi, N, Landry, GL, et al. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Br J Sports Med* 48: 287–288, 2014.

34. Dos'Santos, T, McBurnie, A, Comfort, P, and Jones, PA. The effects of six-weeks change of direction speed and technique modification training on cutting performance and movement quality in male youth soccer players. *Sports* 7: 205, 2019.

35. 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.

36. Dos'Santos, T, Thomas, C, Jones, PA, and Comfort, P. Mechanical determinants of faster change of direction speed performance in male athletes. *J Strength Cond Res* 31: 696–705, 2017.

37. Dos'Santos, T, Thomas, C, McBurnie, A, Donelon, T, Herrington, L, and Jones, PA. The cutting movement assessment score (CMAS) qualitative screening tool: Application to mitigate anterior cruciate ligament injury risk during cutting. *Biomechanics* 1: 83–101, 2021.

38. Dos'Santos, T, McBurnie, A, Thomas, C, Comfort, P, and Jones, P. Biomechanical comparison of cutting techniques: A review and practical applications. *Strength Cond J* 41: 40–45, 2019.

39. Dos'Santos, T, McBurnie, A, Thomas, C, Comfort, P, and Jones, PA. Biomechanical determinants of the modified and traditional 505 change of direction speed test. *J strength Cond Res* 34: 1285–1296, 2020.

40. Dos'Santos, T, Thomas, C, Comfort, P, and Jones, PA. Role of the penultimate foot contact during change of direction: implications on performance and risk of injury. *Strength Cond J* 41: 87–104, 2019.

41. Edwards, WB. Modeling overuse injuries in sport as a mechanical fatigue phenomenon. *Exerc Sport Sci Rev* 46: 224–231, 2018.

42. Ford, P, de Ste Croix, M, Lloyd, R, Meyers, R, Moosavi, M, Oliver, J, et al. The Long-Term Athlete Development model: Physiological evidence and application. *J Sports Sci* 29: 389–402, 2011.

43. Foster, C, Florhaug, JA, Franklin, J, Gottschall, L, Hrovatin, LA, Parker, S, et al. A new approach to monitoring exercise training. 2001.

44. Francis, C. The Charlie Francis Training System. 1992.

45. Francis, C. Structure of Training for Speed. 2013.

46. Gabbett, TJ, Whyte, DG, Hartwig, TB, Wescombe, H, and Naughton, GA. The relationship between workloads, physical performance, injury and illness in adolescent male football players. *Sport Med* 44: 989–1003, 2014.

47. García-Ramos, A, Haff, GG, Feriche, B, and Jaric, S. Effects of different conditioning

programmes on the performance of high-velocity soccer-related tasks: Systematic review and meta-analysis of controlled trials. *Int J Sport Sci Coach* 13: 129–151, 2018.

48. Gastin, PB, Bennett, G, and Cook, J. Biological maturity influences running performance in junior Australian football. *J Sci Med Sport* 16: 140–145, 2013.

49. Granacher, U, Lesinski, M, Büsch, D, Muehlbauer, T, Prieske, O, Puta, C, et al. Effects of resistance training in youth athletes on muscular fitness and athletic performance: A conceptual model for long-term athlete development. *Front Physiol* 7: 164, 2016.

50. Granacher, U, Puta, C, Gabriel, HHW, Behm, DG, and Arampatzis, A. Neuromuscular training and adaptations in youth athletes. *Front Physiol* 9: 1264, 2018.

51. Gravina, L, Gil, SM, Ruiz, F, Zubero, J, Gil, J, and Irazusta, J. Anthropometric and physiological differences between first team and reserve soccer players aged 10-14 years at the beginning and end of the season. *J Strength Cond Res* 22: 1308–1314, 2008.

52. Haddad, M, Stylianides, G, Djaoui, L, Dellal, A, and Chamari, K. Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Front Neurosci* 11: 612, 2017.

53. Haff, GG and Nimphius, S. Training principles for power. *Strength Cond J* , 2012.

54. Harper, DJ, Jordan, AR, and Kiely, J. Relationships between eccentric and concentric knee strength capacities and maximal linear deceleration ability in male academy soccer players. *J Strength Cond Res* Published ahead of print, 2018.

55. Harper, DJ and Kiely, J. Damaging nature of decelerations: Do we adequately prepare players? *BMJ Open Sport Exerc Med* 4, 2018.

56. Harrison, JS. Bodyweight training: A return to basics. *Strength Cond J* 32: 52–55, 2010.

57. Hawkins, D and Metheny, J. Overuse injuries in youth sports: Biomechanical considerations. *Med Sci Sports Exerc* 33: 1701–1707, 2001.

58. Hewit, JK, Cronin, JB, and Hume, PA. Kinematic factors affecting fast and slow straight and change-of-direction acceleration times. *J Strength Cond Res* 27: 69–75, 2013.

59. Hicks, DS, Schuster, JG, Samozino, P, and Morin, J-B. Improving mechanical effectiveness during sprint acceleration: Practical recommendations and guidelines. *Strength Cond J* 42: 45–62, 2020.

60. Hooper, SL, Mackinnon, LT, Howard, A, Gordon, RD, and Bachmann, AW. Markers for monitoring overtraining and recovery. *Med Sci Sports Exerc* 27: 106–112, 1995.

61. Hunter, JP, Marshall, RN, and McNair, PJ. Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *J Appl Biomech* 21: 31–43, 2005.

62. Impellizzeri, FM, Rampinini, E, Coutts, JJ, Sassi, A, and Marcora, SM. Use of RPE-based training load in soccer. *Med Sci Sport Exerc* 36: 1042–1047, 2004.

63. Issurin, VB. Benefits and limitations of block periodized training approaches to

athletes' preparation: a review. *Sport Med* 46: 329–338, 2016.

64. Jeffreys, I, Huggins, S, and Davies, N. Delivering a gamespeed-focused speed and agility development program in an english premier league soccer academy. *Strength Cond J* 40: 23–32, 2018.

65. Johnson, DM, Williams, S, Bradley, B, Sayer, S, Murray Fisher, J, and Cumming, S. Growing pains: Maturity associated variation in injury risk in academy football. *Eur J Sport Sci* 20: 544–552, 2019.

66. 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.

67. 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.

68. Jones, PA, Herrington, LC, and Graham-Smith, P. Technique determinants of knee joint loads during cutting in female soccer players. *Hum Mov Sci* 42: 203–211, 2015.

69. Keiner, M, Sander, A, Wirth, K, and Schmidtbleicher, D. Long-term strength training effects on change-of-direction sprint performance. *J Strength Cond Res* 28: 223–231, 2014.

70. Kelly, DM, Strudwick, AJ, Atkinson, G, Drust, B, and Gregson, W. Quantification of training and match-load distribution across a season in elite English Premier League soccer players. *Sci Med Footb* 4: 59–67, 2020.

71. Kemper, GLJ, Van Der Sluis, A, Brink, MS, Visscher, C, Frencken, WGP, and Elferink-Gemser, MT. Anthropometric injury risk factors in elite-standard youth soccer. *Int J Sports Med* 36: 1112–1117, 2015.

72. Khamis, HJ and Roche, AF. Predicting adult stature without using skeletal age: The Khamis-Roche method. *Pediatrics* 94: 504–507, 1994.

73. Kubo, K, Kanehisa, H, Kawakami, Y, and Fukanaga, T. Growth changes in the elastic properties of human tendon structures. *Int J Sports Med* 22: 138–143, 2001.

74. Kugler, F and Janshen, L. Body position determines propulsive forces in accelerated running. *J Biomech* 43: 343–348, 2010.

75. Kumagai, K, Abe, T, Brechue, WF, Ryushi, T, Takano, S, and Mizuno, M. Sprint performance is related to muscle fascicle length in male 100-m sprinters. *J Appl Physiol* 88: 811–816, 2000.

76. Lee, MJC, Lloyd, DG, Lay, BS, Bourke, PD, and Alderson, JA. Effects of different visual stimuli on postures and knee moments during sidestepping. *Med Sci Sports Exerc* 45: 1740–1748, 2013.

77. Leong, CH, McDermott, WJ, Elmer, SJ, and Martin, JC. Chronic eccentric cycling improves quadriceps muscle structure and maximum cycling power. *Int J Sports Med* , 2014.

78. Lipps, DB, Wojtys, EM, and Ashton-Miller, JA. Anterior cruciate ligament fatigue failures in knees subjected to repeated simulated pivot landings. *Am J Sports Med* 41: 1058–1066, 2013.

79. Lloyd, RS, Cronin, JB, Faigenbaum, AD, Haff, GG, Howard, R, Kraemer, WJ, et al. National Strength and Conditioning Association position statement on long-term

athletic development. *J Strength Cond Res* 30: 1491–1509, 2016.

80. Lloyd, RS, Faigenbaum, AD, Stone, MH, Oliver, JL, Jeffreys, I, Moody, JA, et al. Position statement on youth resistance training: The 2014 International Consensus. *Br J Sports Med* 48: 498–505, 2014.

81. Lloyd, RS and Oliver, JL. The youth physical development model: A new approach to long-term athletic development. *Strength Cond J* 34: 61–72, 2012.

82. Lloyd, RS, Oliver, JL, Faigenbaum, AD, Myer, GD, and De Ste Croix, MBA. Chronological age vs. biological maturation: Implications for exercise programming in youth. *J Strength Cond Res* 28: 1454–1464, 2014.

83. Lloyd, RS, Oliver, JL, Hughes, MG, and Williams, CA. Age-related differences in the neural regulation of stretch-shortening cycle activities in male youths during maximal and sub-maximal hopping. *J Electromyogr Kinesiol* 22: 37–43, 2012.

84. Malina, RM, Bouchard, C, and Bar-Or, O. Growth, maturation, and physical activity. 2nd ed. Champaign, Illinois, United States: Human Kinetics, 2004.

85. Malina, RM, Eisenmann, JC, Cumming, SP, Ribeiro, B, and Aroso, J. Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13-15 years. *Eur J Appl Physiol* 91: 555–562, 2004.

86. Malina, RM, Reyes, MEP, Eisenmann, JC, Horta, L, Rodrigues, J, and Miller, R. Height, mass and skeletal maturity of elite Portuguese soccer players aged 11–16 years. *J Sports Sci* 18: 685–693, 2000.

87. Malina, RM, Rogol, AD, Cumming, SP, Coelho E Silva, MJ, and Figueiredo, AJ. Biological maturation of youth athletes: Assessment and implications. *Br J Sports Med* 49: 852–859, 2015.

88. Malone, S, Roe, M, Doran, DA, Gabbett, TJ, and Collins, K. High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *J Sci Med Sport* 20: 250–254, 2017.

89. Materne, O, Farooq, A, Johnson, A, Greig, M, and McNaughton, L. Relationship between injuries and somatic maturation in highly trained youth soccer players. In: Proceedings of the World Congress on Science and Soccer.2015.

90. McBurnie, AJ and Dos'Santos, T. Multi-directional speed in youth soccer players: Theoretical underpinnings. *Strength Cond J* Accepted for publication in SCJ, 2021.

91. McBurnie, AJ, Dos'Santos, T, and Jones, PA. Biomechanical associates of performance and knee joint loads during a 70–90° cutting maneuver in sub-elite soccer players. *J Strength Cond Res* Published ahead of print, 2019.

92. Mendiguchia, J, Conceição, F, Edouard, P, Fonseca, M, Pereira, R, Lopes, H, et al. Sprint versus isolated eccentric training: Comparative effects on hamstring architecture and performance in soccer players. *PLoS One* 15: e0228283, 2020.

93. Mirwald, RL, Baxter-Jones, AD, Bailey, DA, and Beunen, GP. An assessment of maturity from anthropometric measurements. *Med Sci Sport Exerc* 34: 689–694, 2002.

94. Moran, J, Sandercock, G, Rumpf, MC, and Parry, DA. Variation in Responses to Sprint Training in Male Youth Athletes: A Meta-analysis. *Int J Sports Med* 38: 1–11, 2017.

95. Morin, JB, Edouard, P, and Samozino, P. Technical ability of force application as a determinant factor of sprint performance. *Med Sci Sports Exerc* 43: 1680–1688, 2011.

96. Murphy, AJ, Lockie, RG, and Coutts, AJ. Kinematic determinants of early acceleration in field sport athletes. *J Sport Sci Med* 2: 144, 2003.

97. Murray, A. Managing the Training Load in Adolescent Athletes. *Int J Sports Physiol Perform* 12: S2-42-S2-49, 2017.

98. Naughton, G, Farpour-Lambert, NJ, Carlson, J, Bradney, M, and Van Praagh, E. Physiological issues surrounding the performance of adolescent athletes. *Sport Med* 30: 309–325, 2000.

99. Nedergaard, NJ, Robinson, MA, Eusterwiemann, E, Drust, B, Lisboa, PJ, and Vanrenterghem, J. The relationship between whole-body external loading and body-worn accelerometry during team-sport movements. *Int J Sports Physiol Perform* 12: 18–26, 2017.

100. Nimphius, S. Training change of direction and agility. In: Advanced Strenth and Conditioning: An Evidence-based Approach.Routledge, 2017. pp. 293–308

101. 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.

102. Nygaard Falch, H, Guldteig Rædergård, H, and van den Tillaar, R. Effect of different physical training forms on change of direction ability: a systematic review and meta-analysis. *Sport Med* 5: 53, 2019.

103. Oliver, JL, Lloyd, RS, and Meyers, RW. Training elite child athletes: Promoting welfare and well-being. *Strength Cond J* 33: 73–79, 2011.

104. Oliver, JL and Smith, PM. Neural control of leg stiffness during hopping in boys and men. *J Electromyogr Kinesiol* 20: 973–979, 2010.

105. Otte, FW, Davids, K, Millar, S-K, and Klatt, S. When and how to provide feedback and instructions to athletes?-How sport psychology and pedagogy insights can improve coaching interventions to enhance self-regulation in training. *Front Psychol* 11: 1444, 2020.

106. Owen, AL, Lago-Penñs, C, Gómez, MÁ, Mendes, B, and Dellal, A. Analysis of a training mesocycle and positional quantification in elite European soccer players. *Int J Sport Sci Coach* 12: 665–676, 2017.

107. Palucci Vieira, LH, Carling, C, Barbieri, FA, Aquino, R, and Santiago, PRP. Match running performance in young soccer Players: A systematic review. *Sport Med* 49: 289–318, 2019.

108. Parr, J, Winwood, K, Hodson-Tole, E, Deconinck, FJA, Hill, JP, Teunissen, AJW, et al. The main and interactive effects of biological maturity and relative age on physical performance in elite youth soccer players. *J Sports Med* Open Acces: 11, 2020.

109. Parr, J, Winwood, K, Hodson-Tole, E, Deconinck, FJA, Parry, L, Hill, JP, et al. Predicting the timing of the peak of the pubertal growth spurt in elite youth soccer players: evaluation of methods. *Ann Hum Biol* Published ahead of print, 2020.

110. Paul, DJ, Gabbett, TJ, and Nassis, GP. Agility in team sports: Testing, training and factors affecting performance. *Sport Med* 46: 421–442, 2016.

111. Petrakos, G, Morin, JB, and Egan, B. Resisted sled sprint training to improve sprint performance: A aystematic review. *Sport Med* 46: 381–400, 2016.

112. Philippaerts, RM, Vaeyens, R, Janssens, M, Van Renterghem, B, Matthys, D, Craen, R, et al. The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci* 24: 221–230, 2006.

113. Pluim, BM and Drew, MK. It's not the destination, it's the "road to load" that matters: A tennis injury prevention perspective. *Br J Sports Med* 50: 641–642, 2016.

114. Quatman-Yates, CC, Quatman, CE, Meszaros, AJ, Paterno, M V., and Hewett, TE. A systematic review of sensorimotor function during adolescence: A developmental stage of increased motor awkwardness? *Br J Sports Med* 46: 649–655, 2012.

115. Radnor, JM, Lloyd, RS, and Oliver, JL. Individual response to different forms of resistance training in school-aged boys. *J Strength Cond Res* 31: 787–797, 2017.

116. Radnor, JM, Oliver, JL, Waugh, CM, Myer, GD, Moore, IS, and Lloyd, RS. The influence of growth and maturation on stretch-shortening cycle function in youth. *Sport Med* 48: 51–71, 2018.

117. Ratel, S, Duché, P, and Williams, CA. Muscle fatigue during high-intensity exercise in children. *Sport Med* 36: 1031–1065, 2006.

118. Rodríguez-Marroyo, J and Antoñan, C. Validity of the session rating of perceived exertion for monitoring exercise demands in youth soccer players. *Int J Sports Physiol Perform* , 2015.

119. Ross, A, Leveritt, M, and Riek, S. Neural influences on sprint running training adaptations and acute responses. *Sport Med* 31: 409–409, 2001.

120. Rumpf, MC, Cronin, JB, Oliver, JL, and Hughes, M. Assessing youth sprint ability-methodological issues, reliability and performance data. *Pediatr Exerc Sci* 23: 442–467, 2011.

121. Rumpf, MC, Cronin, JB, Pinder, SD, Oliver, J, and Hughes, M. Effect of different training methods on running sprint times in male youth. *Pediatr Exerc Sci* 24: 170–186, 2012.

122. Rumpf, MC, Lockie, RG, Cronin, JB, and Jalilvand, F. Effect of different sprint training methods on sprint performance over various distances: a brief review. *J Strength Cond Res* 30: 1767–1785, 2016.

123. Le Runigo, C, Benguigui, N, and Bardy, BG. Perception-action coupling and expertise in interceptive actions. *Hum Mov Sci* 24: 429–445, 2005.

124. Samozino, P, Rabita, G, Dorel, S, Slawinski, J, Peyrot, N, Saez de Villarreal, E, et al. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scand J Med Sci Sport* 26: 648–658, 2016.

125. Saw, AE, Main, LC, and Gastin, PB. Monitoring the athlete training response: Subjective self-reported measures trump commonly used objective measures: A systematic review. *Br J Sports Med* 50: 281–291, 2016.

126. Saward, C, Morris, JG, Nevill, ME, Nevill, AM, and Sunderland, C. Longitudinal development of match-running performance in elite male youth soccer players. *Scand J Med Sci Sports* 26: 933–942, 2016.

127. Scantlebury, S, Till, K, Sawczuk, T, Weakley, J, and Jones, B. Understanding the relationship between coach and athlete perceptions of training intensity in youth sport. *J Strength Cond Res* , 2018.

128. Schepens, B, Willems, PA, and Cavagna, GA. The mechanics of running in children. *J Physiol* 509: 927, 1998.

129. Sheppard, J and Young, W. Agility literature review: Classifications, training and testing. *J Sports Sci* 24: 919–932, 2006.

130. Slawinski, J, Bonnefoy, A, Levêque, JM, Ontanon, G, Riquet, A, Dumas, R, et al. Kinematic and kinetic comparisons of elite and well-trained sprinters during sprint start. *J Strength Cond Res* 24: 896–905, 2010.

131. Soligard, T, Schwellnus, M, Alonso, JM, Bahr, R, Clarsen, B, Dijkstra, HP, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med* 50: 1030–1041, 2016.

132. Stone, MH, Stone, M, and Sands, WA. Principles and Practice of Resistance Training. 2007.

133. Suchomel, TJ, Comfort, P, and Lake, JP. Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength Cond J* 39: 10–20, 2017.

134. Suchomel, TJ, Wagle, JP, Douglas, J, Taber, CB, Harden, M, Gregory Haff, G, et al. Implementing eccentric resistance training—Part 1: A brief review of existing methods. *J Funct Morphol Kinesiol* 4: 38, 2019.

135. Suchomel, TJ, Wagle, JP, Douglas, J, Taber, CB, Harden, M, Gregory Haff, G, et al. Implementing eccentric resistance training—Part 2: Practical recommendations. *J Funct Morphol Kinesiol* 4: 55, 2019.

136. Taylor, K, Chapman, D, Cronin, J, Newton, M, and Gill, N. Fatigue monitoring in high performance sport: a survey of current trends. *J Aust Strength Cond* 20: 12–23, 2012.

137. Thorpe, RT, Atkinson, G, Drust, B, and Gregson, W. Monitoring fatigue status in elite team-sport athletes: implications for practice. *Int J Sports Physiol Perform* 12: S2-27, 2017.

138. Turner, A, Comfort, P, McMahon, J, Bishop, C, Chavda, S, Read, P, et al. Developing powerful athletes, part 2: practical applications. *Strength Cond J* Published ahead of print, 2020.

139. Van-der-Sluis, A, Elferink-Gemser, M, Coelho-e-Silva, M, Nijboer, J, Brink, M, and Visscher, C. Sport injuries aligned to peak height velocity in talented pubertal soccer players. *Int J Sports Med* 35: 351–355, 2013.

140. Van-Hooren, B, De, M, and Croix, S. Sensitive periods to train general motor abilities in children and adolescents: Do they exist? A critical appraisal. *Strength Cond J* Published ahead of print, 2020.

141. Vanrenterghem, J, Nedergaard, NJ, Robinson, MA, and Drust, B. Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sport Med* 47: 2135–2142, 2017.

142. Verheul, J, Nedergaard, NJ, Vanrenterghem, J, and Robinson, MA. Measuring biomechanical loads in team sports–from lab to field. *Sci Med Footb* 4: 246–252, 2020.

143. Verheul, J, Warmenhoven, J, Lisboa, P, Gregson, W, Vanrenterghem, J, and Robinson, MA. Identifying generalised segmental acceleration patterns that contribute to ground reaction force features across different running tasks. *J Sci Med Sport* 22: 1355–1360, 2019.

144. Viru, A, Loko, J, Harro, M, Volver, A, Laaneots, L, and Viru, M. Critical periods in the development of performance capacity during childhood and adolescence. *Eur J Phys Educ* 4: 75–119, 1999.

145. Walker, GJ and Hawkins, R. Structuring a program in elite professional soccer. *Strength Cond J* 40: 72–82, 2018.

146. Wang, Q, Ghasem-Zadeh, A, Wang, XF, Iuliano-Burns, S, and Seeman, E. Trabecular bone of growth plate origin influences both trabecular and cortical morphology in adulthood. *J Bone Miner Res* 26: 1577–1583, 2011.

147. Wang, Q, Wang, XF, Iuliano-Burns, S, Ghasem-Zadeh, A, Zebaze, R, and Seeman, E. Rapid growth produces transient cortical weakness: A risk factor for metaphyseal fractures during puberty. *J Bone Miner Res* 25: 1521–1526, 2010.

148. Weston, M, Siegler, J, Bahnert, A, McBrien, J, and Lovell, R. The application of differential ratings of perceived exertion to Australian Football League matches. *J Sci Med Sport* 18: 704–708, 2015.

149. Weyand, PG, Sternlight, DB, Bellizzi, MJ, and Wright, S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J Appl Physiol* 89: 1991–1999, 2000.

150. Williams, CA, Oliver, JL, and Faulkner, J. Seasonal monitoring of sprint and jump performance in a soccer youth academy. *Int J Sports Physiol Perform* 6: 264–275, 2011.

151. Wormhoudt, R, Savelsbergh, GJP, Teunissen, AJW, and Davids, K. The athletic skills model: optimizing talent development through movement education. Routledge, 2017.

152. Young, W and Farrow, D. The importance of a sport-specific stimulus for training agility. *Strength Cond J* 35: 39–43, 2013.

153. Young, W, Farrow, D, Pyne, D, McGregor, W, and Handke, T. Validity and reliability of agility tests in junior Australian football players. *J Strength Cond Res* 25: 3399–3403, 2011.

154. Young, WB, Dawson, B, and Henry, GJ. Agility and change-of-direction speed are independent skills: Implications for training for agility in invasion sports. *Int J Sport Sci Coach* 10: 159–169, 2015.