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Multi-Directional Speed in Youth Soccer Players: Theoretical Underpinnings

Abstract

This review will provide a definition for ‘multi-directional speed’ (MDS) and evaluate its technical and mechanical underpinnings. This review will explore each component of MDS while considering unique aspects of youth physiology and epidemiology. With a theoretical understanding of MDS, practitioners will be more informed on the planning and periodization of MDS training methods in soccer. MDS comprises of linear speed, change of direction speed, curvilinear speed, contextual speed, and agility, which each have distinct physiological, biomechanical, and neuro-cognitive distinctions that can either be differentiated or harmonized to optimise training.

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

Introduction

Soccer is a team sport which is intermittent in nature, where frequent changes in locomotor patterns (e.g., walking, running, sprinting), directional changes (e.g., cutting, pivoting), and sports-specific tasks (e.g., tackles, headers, dribbles) occur (19,184). Professional soccer players have become faster over time (84), and although data are highly position-specific (22,29,53,54), both the total sprinting distance and number of sprints (> 25.2 km·h $^{-1}$) performed in match-play have increased 35% and 85%, respectively, in the English Premier League from the 2006-06 to the 2012-13 season (10). Maximal sprint velocities are typically attained within 30 to 40 m in soccer (198), of which can be initiated from a moving start (198). Subsequently, players can often attain between 85 to 94% of their peak sprint velocities in match-play (76), which suggests that soccer players can often have the opportunity to achieve maximum sprint speeds in games when initiating sprints while already moving. Of note, approximately 85% of all maximum velocity actions that are executed in elite soccer present some degree of curvature (31). Another consideration is that of actions considered to be ‘low-speed’ activity, that still require high energy outputs (33). The large majority of sprinting actions are typically performed within distances of 20 m (53,184,199) and data have shown that accelerations and decelerations (>2 $m \cdot s^2$) can contribute to as much as 7 to 10% and 5 to 7% of total player game load, respectively (44). Moreover, on a qualitative level, players can perform a mean of 30.7% of game actions and maneuvers in backward, lateral, diagonal and arced directions, and perform an average of 726 ± 203 turns in a game (19).

Importantly, it is each of these above-mentioned high-intensity and sprint-type actions that are considered to be vital determinants of successful performance in soccer (34). For example, sprinting has been identified as the most frequent action associated with goal scoring scenarios (63). Furthermore, acceleration and maximum sprinting speed capabilities, along with the ability to perform sudden and unpredictable high-intensity change of direction (COD) manoeuvers while in motion, have been shown to differentiate between players from different playing standards (84,165). Arguably, then, speed can and should be seen as one of the most sought after physical qualities in sport (136,143,161). Yet these high physiological and mechanical demands also present an inherent risk of injury, due to the repeated nature of high intensity movements such as jumping, cutting, and contact with opposition players, particularly when fatigued (46). Consequently, it should be a priority for practitioners to develop an athlete's capacity and robustness to perform multi-directional, high-speed actions, while ensuring these manoeuvers are underpinned by movement quality. These conditioning elements should be key in the development of successful performance and injury risk mitigation strategies in soccer.

In a male youth soccer context (youth herein referring to both children, boys up to 13 years of age, and adolescents, boys aged 14-18 years) the aims of strength and conditioning methods are to enhance long-term athletic development (LTAD) and subsequent progression into the professional game (35,73,110,165). Furthermore, it has been highlighted in cross-sectional analyses that speed development increases in youth and may in fact plateau early on in a professional player's senior career (e.g., before 20-22 years old) (84). Resultantly, if movement skill is not well developed at late junior or early senior age, it may become more challenging to improve these capabilities to the standard required when performing at the senior level. Practitioners should, however, be aware that training the youth athlete requires careful consideration, given the significant individual variability in factors that affect the pathway of growth, development and maturation within their developmental journey (120,121,144). Youth soccer players should not been seen as ‘mini adults’, as they can possess markedly different physical and physiological processes that attribute to their performance in comparison to their senior peers (155,168). This also extends to injury risk, where youth athletes present maturity-specific mechanisms that underlie certain injury risk factors within the youth soccer setting (163).

In order to programme multi-directional speed training for youth athletes, the age- and maturity-specific movement demands of youth soccer need to be accurately classified to guide appropriate training prescription (155). Not only may this allow for specific movement skills to be trained more effectively during different phases of development, but also allow for the dose-response relationship of training to be uncovered with a long-term vision in mind. With that said, although research in this area is emerging (9,28,29,80,117,173), there is currently a lack of consensus regarding the match activity profiles in youth soccer (155), and furthermore, investigations into the more nuanced components of multi-directional speed (e.g., deceleration, curvilinear speed, ‘gamespeed’, and agility) in soccer are still in their infancy in the senior game (31,65,81,83), let alone with respect to youth soccer.

The aims of this review are to propose a definition for the term, ‘multi-directional speed’ (MDS), underlining how the key components of MDS relate to performance and injury risk, through an exploration of its theoretical underpinnings. Although practitioners are interested in training strategies to enhance MDS (129), it is imperative to understand the mechanical and technical underpinning of MDS to effectively design physical preparation and MDS sessions for the athletes. This review will firstly begin with a discussion on the performance and injury risk considerations for the growing athlete. This should enable the subsequent sections in this review to be viewed through the lens of LTAD, in which practitioners are afforded the time to implement foundational, age-appropriate and progressive training methods, as a means of optimising athletic competency, reduce injury risk, and ensure the attainment of future potential.

Movement Characteristics of Youth Soccer

As mentioned previously, an understanding of the movement characteristics in youth soccer match-play will enable more accurate and bespoke training prescription to be delivered with respect to volume and intensity (155). Age-group comparisons of youth match running performance (29) indicate that significantly greater absolute high-intensity activity (e.g., > 16.1 km·h $^{-1}$; U13 = 509 ± 156 vs. U18 = 1239 ± 337 m), 'sprinting' distances (e.g., > 19.1 m·h $^{-1}$; U13 = 186 ± 92 m vs. U18 = 666 ± 256 m), and peak game speeds (e.g., U13 = 22.3 ± 1.4 km·h $^{-1}$ vs. U18 = 28.3 ± 2.2 km·h $^{-1}$) are attained as they progress through the age-groups. The aforementioned trends have been reported elsewhere (9,80,117,173), yet to the authors' best knowledge, there currently exists no insights into the mechanical demands (e.g., acceleration and deceleration) of youth soccer match-play which spans and directly compares multiple age groups (e.g., the progression from U12 to U18). Thus, a key area regarding high-intensity movement in relation to youth soccer currently remains unknown.

It is important to note that playing position plays a pivotal role in player outputs (29), with which the progression of players through the age groups may see their playing roles specialise. Furthermore, recent studies have suggested that biological maturation itself can positively impact match running performance for individuals performing within the same age-group (28,71,76); however, utilising this information to guide training prescription remains difficult. As with the complexity and diversity of youth soccer environments around the world, factors such as game rules (i.e., age-grouping criteria, substitution policy), match format and configuration (i.e., number of players involved, pitch dimensions, match durations and number of intervals), maturity status, playing position, and assignment of different pre-determined movement thresholds means that studies of age-matched players are almost completely unstandardized (155). Resultantly, more detailed investigations into the match-play activity profiles of youth soccer players that are both specific to the game format, playing standard, and maturity status of individuals spanning across an academy are warranted. It is recommended, where possible, that data specific to the individuals in question be collected to inform practitioners in this regard. This will enable more individualised training prescriptions based on population-specific criteria that can be progressed as individuals mature through age categories.

Injury Characteristics of Youth Soccer

Unique to the youth athlete population are the constructs of growth and maturation and their potential as risk factors for injury. Briefly, growth rate describes changes in an individual's physical dimension over a given time, whereas maturation refers to the process towards a mature state (120). Due to the large individual variation in the timing and tempo in the process of maturation, the physical and neuro-developmental differences between individuals, such as immature structures and underdeveloped neuromuscular control, and disparities in maturation status between age-matched individuals have been identified as mechanisms that may affect the risk of injury (132,160). Insights from research have also suggested that episodes of rapid growth and the period around peak-height velocity (PHV) are associated with increased injury risk in elite sports (79,96,103,127,194).

'Overuse' injuries (i.e., Osgood-Schlatter's disease (2)) are prevalent in youth soccer populations (159) and may be explained by a reduced structural tolerance of growth plates and developing bone during rapid growth (200,201). Furthermore, the high exposures to repetitive patterning of soccer activities (i.e., kicking) typically seen in highly-specialised academy soccer players can lead to other morphological maladaptations (i.e., Cam-type deformities and femoral acetabular impingement) (3,164,188). The sensitivity to these issues can be exacerbated during the stage of skeletal maturation (i.e., typically in boys between 12 and 14 years) when the proximal femoral growth plates are open (3,4,188). Although largely speculative, the concomitant increases in circulating growth hormone and insulin-like growth factor-1 during rapid periods of growth may heighten the bone’s osteogenic responsiveness to joint loading (64), which, theoretically, may predispose the young athlete to an increased risk of developing the above-mentioned maladaptations if movement variability is limited. Thus, it is of the author’s belief that promoting movement variability throughout training will facilitate a more evenly distributed stress to greater range of anatomical structures by altering the point of force attenuation or production (164). Certainly, this potential link warrants further investigation and may have important implications for the programming of youth activity.

Furthermore, the lags in musculoskeletal growth apparent in the growing athlete can lead to compromised neuromuscular control during dynamic activities (e.g. running, cutting and landing) and is suggested to be a key mechanism for lower-limb ligament injuries (85,86). As such, a high proportion (20%) of injuries in male youth soccer players are acute traumatic ligament sprains at the ankle and knee (70,159,169), of which the medial collateral ligament and anterior talofibular ligament appear to be the most commonly reported injuries (43,159). The presence of neuromuscular deficits do not necessarily indicate an explicit causative factor for these ligamentous injuries, yet it should be noted that these injuries may occur when active muscular protective mechanisms are unable to adequately attenuate joint torques during dynamic manoeuvers involving deceleration and high forces (158). A possible explanation may be due to delay in growth between muscle length and cross-sectional area may affect the sensorimotor function processes responsible for maintaining optimal alignment during rapid adjustments of the system’s centre of mass (COM), which typically occur when performing cutting and landing maneuvers (85,215). This is important to consider, as such maneuvers have been identified as key actions that amplify multi-planar knee joint loading (i.e., knee flexion, rotational, and abduction loading) while the foot is planted (51,52,101,128). Multi-planar knee joint loads are associated with increased strain on the anterior cruciate ligament

(ACL) (177,189), while chronic exposure to abhorrent movement patterns may lead to the development of patellofemoral pain, a common injury observed in youth soccer (140,151).

Moreover, due to the muscle loading patterns inherent during repetitive training and competition in soccer, quadriceps dominance relative to the hamstrings can present as an injury risk factor (90). This can subsequently alter the reciprocal balance of activation between the hamstrings and the quadriceps, reducing the strength and dynamic stabilisation around the knee joint (90). This functional hamstrings:quadriceps ratio (H:Q) has been shown to improve with maturity, as youth athletes experience positive shifts in muscle architectural parameters (166), as well as develop co-activation of the hamstrings, which function to reduce anterior tibial translation and high shear forces generated by the quadriceps as a product of high-speed actions (48,90). Much like their senior peers, the requirement for the youth soccer player to be regularly exposed to high-velocity movements, as well as knee flexor strengthening programmes, to reduce the injury risk associated with the hamstrings muscle group is important (123,163).

The Components of Multi-directional Speed

Currently, there is no universally agreed definition for MDS; however, it can be seen as a term which encompasses all the key speed-related qualities that have been shown to be vital for sporting performance in team sports. That is, linear and COD speed; incorporating acceleration, lateral movements, deceleration, and back-pedalling (i.e., backwards running) (116). The ability to decelerate is vital, particularly for sharper COD (57), while having the competency and capacity to perform a variety of different maneuvers, across a range of angles and velocities, from both limbs, would undoubtedly be advantageous for soccer performance. The authors propose that MDS can be defined as, the competency and capacity to accelerate, decelerate, change direction, and ultimately, maintain speed in multiple directions and movements, within the context of sports-specific scenarios. Fundamentally, given the open nature of team sports, it should be the goal of every coach and practitioner to create fast, efficient, and robust, ‘360-degree’ athletes. The components of MDS should be firstly broken down and explained with respect to its components and their subsequent implications for performance and injury risk.

Specific training methods can be utilised to develop characteristic qualities along the continuum of MDS (Figure 1), which can assist in determining which methods could have a greater emphasis with respect to the broad context of the youth soccer player. Research has indicated that the key determinants of sprinting and COD performance are the physical capabilities (i.e., impulse [force × time] and power qualities) of the athlete, and the technical ability (i.e., joint kinematics, postures, and placement) to apply the subsequent ground reaction forces (GRFs) effectively in the intended direction of travel (59,61,98–100,128,138,150,161,181,212). As such, in order to develop the various qualities that underpin MDS, athletes need to be able to produce high forces, rapidly, and transmit them to the ground effectively in the intended direction of travel (59–61,107,128,136,148).

Linear Speed

During the acceleration phase of a sprint, greater increases in horizontal propulsion are required to achieve high acceleration (16,89,102,107,108,136,138,205). This phase is characterized by a greater forward lean of the torso (49) and shank to facilitate horizontal propulsive forces and a longer time for the application of force during the support phase of ground contact (206,214). Conversely, the transition out of acceleration towards the maximal velocity phase of a sprint is characterized by a shift towards a more vertically oriented GRF vector (41,205), as the torso and shank (at touch-down) becomes progressively more upright (142,143), maximal stride frequency (SF) is attained, and a marked increase in stride length (SL) is observed as running velocity continues to rise (143). This greater emphasis on vertically oriented GRF during maximum velocity limits the time spent decelerating due to reducing ground contact time (GCT) (41,205). The shorter GCT associated with this higher speed (206,214) resultantly limits the mechanical ability to apply such force, given the shorter period of time. Thus, although horizontal GRF is the primary factor governing the rate of acceleration (89,108,136,205), it is fundamentally the impulse-momentum relationship which determines the time in which to force is applied to overcome inertia and gravity. As such, the ability to maintain horizontal impulse over increasingly shorter GCT is critical to sprinting performance (89,108,138). Hence, notable differences are observed between the impulse profiles of acceleration (e.g., peak resultant GRF ~ 2.3 $N \cdot kg^{-1}$; GCT ~ 200-135 ms) and maximal velocity (e.g., peak resultant GRF ~ 3.7 $N \cdot kg^{-1}$; GCT ~ 101-108 ms) phases of sprinting (108,141,206,214). These observations point towards the emphasis of kinetic, kinematic and spatiotemporal attributes that operate on a continuum, whereby the generation and transmission of GRF variables are dependent on the certain phase of the sprint (Figure 1).

Pertinently, given the intermittent nature of soccer match-play, the majority of sprint efforts occur within distances of 20 m (53,184,199), which limits the attainment of maximum speed. Consequently, to adhere to the principle of specificity, the development of acceleration in the context of soccer is a priority (13,14,185), and has led to the proposal of sub-phases within acceleration, where distinctions in biomechanical characteristics have been identified (11,14,119,141,142). In professional soccer players, Bellon et al. (14) established statistically different transitions in sprint characteristics as the progression within the specific distances that categorise the early (0 – 2.5 m), mid (2.5 – 6 m) and late (6 – 12 m) sub-phases of acceleration. Specifically, the early-acceleration phase may be characterized by minimal flight times (FTs) coupled with GCT at their peak, and SL at their lowest with a rapid increase in SF (11,14,143,161). Further, in order to promote a ‘pushing motion’, limited knee flexion over ground support, rapid hip extension velocity, high horizontal GRF behind the COM, and also a rapid rise of the hips with the COM, is reported to occur (142). During the mid-acceleration phase, this antagonistic relationship shifts as GCT declines while FT increases, SL continues to increase and SF typically reaches its maximum, even showing a slight decline prior to stabilizing (11,14,143,161). A reduced rate of COM elevation, increased knee extension velocity, as well as increased knee flexion during ground support are also observed, which is likely a result of striking the ground further in front of the body (142). Finally, the approach towards maximum velocity during the late-acceleration phase is characterized by further reductions in GCT, SF plateauing, and maximal values of FT and SL being attained (11,14,143,161). Additionally, the reduced range of motion observed at the hip will see increasing contributions of the lower leg during this phase (142), which may be explained by the greater need for the foot to aggressively strike the ground in a 'backwards' motion to apply high GRFs within close proximity of the COM (89).

These aforementioned acceleration sub-phases have been shown to be athletic population-specific (11,14,119,141,142); however, the evaluation of acceleration phases with a higher degree of precision (e.g., tracking GCT, FT, SL, SF, COM trajectory and joint angles) allows strength and speed training interventions to be developed that target distinct kinetic and kinematic variables more specific to soccer across the various sub-phases, which may be sequenced at different times during the season (14). Importantly, during acceleration, it is the athlete's technical ability to adopt these phase-specific kinematic postures that facilitate the application of forces in the opposite direction to their COM displacement (17,107,136); an effective horizontal transmission of these forces over increasingly abbreviated GCT as velocity continues to rise has been termed mechanical effectiveness (172). Although it is beyond the scope of this review to discuss off-field training methods in relation to MDS, resistance training should be seen as the cornerstone for which to build positive adaptations to the mechanical qualities (i.e., force, velocity and power) that underpin the kinetics specific to each sub-phase of acceleration (i.e., early, mid and late sub-phases). These methods should maintain a high priority in any supplementary programme that aims to improve an athlete's mechanical effectiveness, and subsequently acceleration performance (87,172).

It is well established that sprinting performance is underpinned by an athlete's mechanical force characteristics (89,102,108,136,138,205), but from a physiological perspective, the action of sprinting requires high levels of motor unit activation (137,190,213). The key muscles involved in sprinting are the hamstrings and the gluteus maximus (i.e., hip extension), quadriceps (i.e., knee extension) and the gastrocnemius and soleus (i.e., plantar flexion) muscle groups, all of which elicit high levels of activation either just prior to or on the instant of ground contact (137). The horizontal orientation of the body combined with the low displacement velocities during acceleration indicates that a large proportion of the stance phase (approx. 87 – 95% of total GCT) is spent applying propulsive GRF (89). Subsequently, this phase is mechanically characterized by an increased activation of the hip, knee and ankle extensors, which work to concentrically contract to produce high levels of force to accelerate the body horizontally (107,137). Conversely, the notable spatiotemporal (i.e., reduced GCT and increased SL), kinetic (i.e., increased vertical GRF) and kinematic (i.e., greater knee and ankle angles) shifts in parameters as a consequence of increased sprinting speeds (141,142) place a much greater requirement on the rate of force development (23,38,41,178). This is achieved through an eccentric-concentric coupling action (i.e., stretch-shortening cycle; SSC), whereby the storage and release of elastic energy through the muscles and tendons around the knee and the ankle (i.e., gastrocnemius-soleus-achilles complex; GSA) joints allow high propulsive GRF to be transmitted in a limited amount of time (174). Taking these findings together, it may be argued that the characteristics of sprinting may follow a ‘proximal-to-distal’ nature (107), with which the force-producing capabilities of these key muscle groups play important roles in certain phases of the sprint.

Overall, it has been shown that the hip extensor and flexor muscles (i.e., gluteals and hamstrings) play a pivotal role in performance across all sprint phases (12,175) and display increasingly greater activation as running speeds increase to maximal sprinting (174). This is further supported by findings that have shown athletes with a better ability to orientate horizontal GRFs have are able to highly activate their hamstrings just before ground contact and present high hip extensor torque capabilities (137). It appears that the concentric torque and activation of the gluteal muscles appear to be more strongly related to horizontal GRF in the initial acceleration phase (137), whereas eccentric hamstring force and activation are more strongly related to top speed mechanics (137,175,187). Thus, particularly at high running speeds (187), it may appear that the high torque requirements of the hamstrings to both eccentrically reduce the kinetic energy of the lower limb during the late-swing phase (32,56), as well as producing high rates of force during the early-stance phase of ground contact (41,205), can work in combination to reduce deceleration time during ground contact and increase horizontal propulsion (138,187).

Notably, it is suggested that the high levels of activation and subsequent torque generated by the hamstring muscles (i.e., as high as eight times bodyweight) can predispose an athlete to an increased risk of hamstring muscle strain injury (HSI) when performing sprint actions (104,187,207,213). Debate exists in relation to whether the mechanistic basis for HSI are explained for in the end-swing phase or early-stance phase (104); however, it has been shown that hip extensor concentric (186) and knee flexor eccentric strength (153) are both considered risk factors for HSI. Moreover, the activation levels (45) and force generating capacity (135) of these muscle groups are compromised in individuals who have previously sustained a HSI. Additionally, architectural characteristics within the hamstrings muscle group, namely, shorter biceps femoris fascicles (BFF), have been identified as a risk factor that may predispose an individual to sustaining a HSI (191). Off-field HSI risk mitigation strategies which focus on conditioning the gluteal and hamstring muscle groups (135) as a means of eliciting specific architectural adaptations (e.g., fascicle length, pennation angle and cross-sectional area) (6,157), as well as positive morphological (e.g., muscle-tendon interactions) and neurological (i.e., motor unit activation, muscular co-ordination and H:Q) adaptations (18,68), are becoming more commonly practised in soccer (130,131). However, none of these methods can replicate the sprint-specific muscular activation patterns experienced during sprinting (190). A comprehensive sprint training programme in complement to regular soccer practise has been shown to induce greater increases in BFF length, alongside improvements in sprint performance and mechanical outcomes, in comparison to isolated knee flexor eccentric strengthening (i.e., Nordic hamstring exercise) and sports-specific practise alone (134). Athletes who regularly sprint at near maximal intensities (i.e., > 95% maximum velocity) during training have displayed a reduced risk of lower-limb injuries in comparison to their teammates who produced lower running intensities (i.e., < 85% maximum velocity) (123). Further to this point, athletes who accumulate larger chronic training exposures to sprinting may also tolerate higher volumes of sprinting (122,123). These findings point towards an approach that features frequent exposure to sprinting, and therefore MDS training, as a central component to both improving performance and reducing injury risk in soccer players (122,123,131,134).

Insert Figure 1 around here

Change of Direction Speed

Change of direction is defined as a "reorientation and change in the path of travel of the whole-body COM towards a new intended direction" (47,209). COD ability provides the technical, mechanical, and physical basis for effective agility (60,148,212). In soccer, CODs are linked to both attacking and defensive scenarios, such as creating space to receive a pass, evading and dribbling past an opponent, pressing opponents and making key interceptions (1). Soccer players perform a large volume of COD actions (~600 cuts of 0-90°; ~100 turns of 90-180°) during match-play (19), to both left and right directions (19,167), with CODs which are then followed by sprints linked to decisive actions such as goal scoring and assists (63). Recent insights into the movement demands of a professional Russian soccer team revealed that ~ 600 CODs were performed during match-play, of which ~60 and ~15 were performed at high (> 16 $km.h^{-1}$) and maximum intensity (> 21 $km.h^{-1}$), respectively (74). Interestingly, the authors revealed that COD frequencies were typically greater during away matches and when during matches performed on artificial field-turf. As such, COD ability is considered a highly important quality to develop in soccer players (193), yet to optimise COD ability, it is important to understand the key biomechanical and physical determinants.

The determinants of COD ability are multi-faceted and underpinned by the interaction between speed, deceleration, mechanics, and physical capacity (Figure 2) (60,61,77,97–99,128,181). The COD foot plant instigates a break in cyclical running, and COD can subsequently be divided into four key phases: 1) initial acceleration; 2) preliminary deceleration; 3) COD foot plant; and 4) re-acceleration. High levels of eccentric, isometric, and concentric strength are required for the braking, plant, and propulsive phases, respectively (124,182,183,204). Undoubtedly, COD is a multi-planar and multi-step action (8,60,62), with the steps preceding and following the main push-off involved in re-direction. For example, the penultimate foot contact (PFC) plays a key role in deceleration and creating posterior braking impulse to reduce momentum prior to changing direction (57,61,62,98,128). The PFC is particularly important for sharper CODs, and is considered a key ‘braking step’ for facilitating faster COD performance and alleviating potentially high-risk knee joint loads (57,59,61,62,98). Conversely, particularly for shallower CODs, the PFC is considered a key ‘positional’ or ‘preparatory step’ for facilitating effective postures during the main COD foot plant to optimise braking and push-off (57,59,61,62,98). Specifically, the COD foot plant requires a manipulation of the base of support relative to COM (e.g., lateral foot plant) to create an external braking impulse to reduce momentum, and a propulsive force and impulse to accelerate into the intended direction of travel, within a short GCT (42,60,128). These factors are all significant associates of faster COD performance (59–61,128,181,182,204). The COD foot plant is described as an eccentric-concentric coupling action (i.e., SSC) and consists of two-phases: weight acceptance (i.e., braking) and push-off (i.e., propulsion) (8,60). During these phases, the body typically goes from lower-limb triple flexion into a rapid, forceful triple extension (i.e., simultaneous joint movements) (8,60), with successful COD performance influenced by key postures (i.e. trunk positioning, pelvis rotation, hip, knee, ankle range of motion, foot plant distance, etc.) to facilitate effective re-direction and to orientate the GRF towards the intended direction of travel for effective net acceleration (60,61,126,128,204). In addition to high magnitudes of braking and propulsive force (impulse) and key technical postures, high levels of muscular activation around the hip, knee, ankle and trunk (i.e., pre- and co-activation) are required to support the large multi-planar external moments created when changing direction and to facilitate effective braking and propulsion, particularly around the knee joint (15,109,124,125,146). Fundamentally, an athlete's physical capacity (i.e., neuromuscular control, rapid force production, strength, muscle activation) is considered highly important during the COD foot plant for the following reasons: 1) applying high and rapid levels of force in short GCT; 2) to support and tolerate the large multi-planar joint loads (particularly from faster approaches velocities (57), sharper CODs angles (57), externally directed attention and agility movements (5,27), limited preparation time (69,139), and fatigue (202)); and 3) permit the athlete to adopt key postures associated with faster performance (57,58,62,98,99,124,148,183).

Insert Figure 2 around here

Because of the unpredictable nature of soccer, players require the capacity to change direction rapidly and effectively across a spectrum of angles, from both their left and right limbs; possessing the ability to perform CODs from low, moderate, and high approach velocities (19,81,167). In addition, soccer players require 'movement solutions', underpinned by physical literacy, in order to perform a variety of different COD actions in the context of sport-specific scenarios (60). For example, 'crossover cuts' are critical when a player aims to maintain velocity during a COD (i.e., < 45˚), such as when a striker performs a curved or arced sprint to evade the offside trap and defensive line. Conversely, a defender may perform a 'side-step' cutting action when pressing and reacting to an opposition player. 'V-cuts' are also a common feature in attacking scenarios, whereby midfield players typically accelerate towards the ball, and then pivot or spin away in order to deceive and create separation from an opposing defender in response to a pass. Finally, ‘split-steps’ are also performed by attacking players during dead-ball situations (i.e., corners, free-kicks, throw-in), whereby man-to-man marking takes place, and the athlete may perform a deceiving maneuver to evade and create separation from an opponent.

It is important to note that biomechanical demands of COD are ‘angle-dependent’ (57). As such, the acceleration, deceleration, COD foot plant mechanics, and re-acceleration requirements of COD are governed by the approach velocity, intended COD angle, sporting scenario (i.e., pre-planned, offensive or defensive agility), and the athletes’ physical capacity (57,62). An ‘angle-velocity trade-off’ concept has been discussed with respect to changing direction, whereby, as the intended COD angle increases, in addition to increased approach velocities, a concurrent reduction in velocity, greater deceleration and braking is required to change inertia and accelerate into the new intended direction of travel (20,57). During shallow CODs (i.e., < 45˚), the deceleration and braking requirements are limited, with GCTs (~150-200 ms) being relatively shorter for COD (57). The ability to approach fast, attain high minimum speeds, and maintain velocity is critical for faster COD performance during shallow cuts (61,78,98,99). This has led to strength and conditioning physical preparation recommendations to focus on the ‘velocity’ end of the force-velocity curve (FVC), and the utility of ballistic and fast SSC exercises (20,57). Conversely, with sharper CODs (i.e., ≥ 60˚), although approach velocity is still vital (61,98,99,128), the ability to decelerate by braking hard, late, and rapidly is fundamental to faster COD performance (61,62,98,99), with sharper CODs from greater approach velocities typically requiring greater braking distances and longer GCTs (~300-500 ms) during the COD foot plant to facilitate the directional change (57,62,77,78). As such, this has led to the physical preparation recommendations which target the ‘force’ aspect of the FVC through resistance training and utilising slow SSC plyometric exercises (20,57). Resultantly, angle and velocity are two crucial factors which regulate intensity during COD, and should be progressed accordingly when coaching and designing MDS training programmes (Figure 1).

An athlete’s ability to decelerate should be considered as an essential component to COD performance (Figure 2). A recent meta-analysis (81) provided further insights when highlighting that high-intensity (>2.5 $m\cdot s^{-2}$) and very high-intensity (>3.5 $m\cdot s^{-2}$) decelerations were performed more frequently than equivalently intense accelerations, across every team sport during competitive match-play, with the exception of American Football. Importantly, soccer was considered the team sport where this difference was the largest (standardized mean difference = − 1.74). For example, high-intensity decelerations (>2 $m\cdot s^{-2}$) have been shown to occur up to 2.9 times more frequently than accelerations within the same speed intensities in soccer (88). Interestingly, a ‘self-regulatory’ concept has been discussed with respect to COD (57,98,99), whereby athletes sprint at a velocity based on the deceleration load that they can tolerate. This deceleration ability is fundamentally underpinned by eccentric strength; for example, eccentrically (knee flexor and extensor) stronger female soccer players have been shown to approach faster and display greater reductions in velocity and braking forces during 180° CODs (98), while eccentrically stronger (knee flexor and extensor) soccer players were able to maintain velocity, attain higher minimum speeds, and tolerate greater loads during a 90° cutting task (99). Taken together, these findings highlight the interaction between an athletes physical capacity and their movement repertoire, which this has led to the strength and conditioning recommendations of developing eccentric strength capacity alongside field-based programming for COD and deceleration performance (36,62,81,83,97,100,128).

Although accelerations and decelerations both expose individuals to high levels of physiological and biomechanical stress (92,196), these stressors can be seen as fundamentally different (30,196). Accelerations may have a higher metabolic cost (77) in comparison to decelerations which can elicit higher mechanical demands (44); this heightened mechanical load is likely explained by the high force impact peaks and loading rates which occur as a consequence of often suddenly imposed deceleration actions (197). Specifically, the high magnitude eccentric braking force requirements of deceleration can impart damage on soft-tissue structures (i.e., tendons) through eccentric muscle fibre contractions that can disrupt the integrity of the muscle fibres (75), particularly if there is a reduced capacity to effectively attenuate these high force demands (83). In contrast, acceleration has high concentric strength requirements (23,115,147) of which are vital for the production of horizontal GRFs (16,89,102,107,138,205). This may bring with it an increased vulnerability of the muscle-tendon tissue properties in handling eccentric braking demands (72,156) that will come as a direct consequence of increased movement speeds (57,145). Therefore, interventions should be implemented that "mechanically protect" individuals from the damaging nature of high-intensity decelerations (62,83). Indeed, improving an athlete's acceleration and COD mechanics are important for successful MDS; however, it is emphasised that coaches, 'do not speed up, what an athlete cannot slow down' (81–83). Practitioners should ensure that they develop their athletes' braking mechanics, in conjunction with their eccentric strength capacity, for effective deceleration, and subsequently COD, from both performance and injury risk mitigation perspectives (61,62,82,98,99,128).

As mentioned previously, the compromised neuromuscular control in youth athletes during high-risk maneuvers that involve rapid decelerations and high eccentric forces place this population at a heightened risk of sustaining acute traumatic lower-limb ligament injuries about the ankle and the knee (70,85,86,159,169). As such, correcting hazardous postures (e.g., knee valgus) are often encouraged in injury mitigation programmes (154). It has been shown that high gluteal activation is required to oppose knee valgus and rotator moments (125), and from a performance perspective, facilitate effective propulsion (124). Furthermore, in addition to playing a key role during linear sprinting (137), the hamstrings also have an important role in preventing anterior translation of the tibia, reducing anterior tibial shear, and attenuating impact GRF during deceleration and COD activities (124,125). Resultantly, training recommendations that focus on improving external hip rotator (gluteal) strengthening and activation (105,106), as well as increasing hamstring strength (203), are recommended. Improving gluteal strength and activation, theoretically, should limit internal hip rotation and adduction, and as such, reduce the frontal plane moment arm and knee abduction moments (KAM) during COD actions (86,133). Furthermore, improving hamstring activation and strength will enable greater knee flexion to reduce impact GRF (55), and permit load absorption via the muscular structure, in contrast to passive structures, which can in turn facilitate a reduction in ACL loading (203).

Ultimately, as with many aspects of human movement there will be movement variability. Athletes may display slight differences in movement strategy while still achieving similar outcomes. That said, there will still be key movement principles and subsequent postures and positions which optimise force generation and transmission. The extent of the techniques will differ cross individuals, and will influenced by a myriad of factors, such as anthropometry, physical capacity, training age, contextual and situational variables.

Curvilinear Speed

Although linear speed is indeed important for soccer players (63), in the context of soccer performance, a large proportion of sprints do not occur in a straight line, but in fact are curved or arced with a deviation and curvature of the path of travel (1,24,31,67). Curved sprinting (synonymous with curvilinear speed, curved speed, and arced running), has been recently defined as “the upright running portion of the sprint completed with the presence of some degree of curvature” (31), described as a hybrid between linear speed and COD (66). However, a COD requires a clear break from cyclical running and with a clear lateral foot plant involved in re-direction, in contrast to curved sprinting which maintains a cyclical running pattern (60). Thus, curved sprinting, theoretically, will most likely share greater biomechanical similarities to linear sprinting opposed to COD. Nevertheless, curved sprinting actions are typically performed by soccer players in offensive situations, such as when performing overlapping or channel runs along a defensive line to maintain an onside position, or defensive situations, such as performing recovery and covering runs when marking and channelling opposition players or making interceptions (1,19,25,26,31). Consequently, the objective of curved sprinting is to deviate from the path of travel in a curvilinear motion while attaining or maintaining high velocities.

Traditionally, emphasis in soccer research has been placed on quantifying and classifying linear speed performance in soccer players (1,21), yet studies examining curved sprinting are scarce. Seminal time-motion analysis from Bloomfield et al. (19) found soccer players perform ~10-20 swerves during match-play, but provided limited information as to how these actions were classified. Pilot analysis from Brice et al. (24) reported curved motions of travel in English FA Premier League soccer players ranged from 3.5 -11 metres. More recently, Caldbeck (31) reported ~85% of sprint actions in elite soccer were in fact curvilinear, while in elite youth soccer players matches, Fitzpatrick et al. (67) observed an average sprinting (> 24 $km \cdot h^{-1}$) angle and frequency of ~5 degrees and 20, respectively, that were typically performed over distances of 10-20 m. However, it is worth noting that, although not as frequent as the acute sprint angles, all players performed sprint angles of up to 30˚ (67). Ade et al. (1) reported soccer players perform ~10-30 arced runs pre-, mid-, and post- high intensity effort during match-play. From a positional perspective, forwards have been shown to perform a greater number of swerves (19), sharper angled sprints, and arced runs in and out of possession (1), compared to other playing positions (67). This potentially highlights the importance of extreme curved sprinting ability in attacking soccer players and implications for position-specific training. Nevertheless, because of the open skilled nature of soccer, irrespective of playing position, it would be advantageous for soccer players to be able to attain and maintain high velocities during curvilinear motion, across a spectrum of varying degrees and radii.

Despite the importance and frequency of curved sprinting in soccer (19,24–26,31,67), it is somewhat surprising that curved sprinting assessments do not commonly feature in the testing batteries (192). To the best of our knowledge, Fílter et al. (66) are the only researchers that have investigated the isolated ability to curvilinear sprint in soccer players in the field, using a 17-m curved sprint with the simple use of the penalty arc (9.15 m radius). The authors observed highly reliable measures of curved sprint speed (ICC ≥ 0.89, CV% ≤ 1.15) in semi-professional soccer players. However, while the authors observed very strong associations between left and right curved sprinting performance (r^2 = 0.77), lower associations were observed between curved and linear sprint speed (r^2 = 0.34-0.37). These findings suggest that athletes who display superior linear speed performance may not necessarily display fast performance during curvilinear tasks, and vice versa. It appears, therefore, that linear and curvilinear sprinting are independent athletic qualities which should be assessed and trained as such. It is currently unknown which training methods are most effective at developing curved sprinting, and it appears that no study has examined the effects of linear speed training on curve sprinting ability in soccer players, and thus, it is a recommended future direction of research.

The finding that linear and curved sprinting appear to be independent athletic qualities could be attributed to key kinetic, kinematic, muscle activation, and spatiotemporal differences between the two tasks (7,25,26,37,39,40,65,91,179,192). In contrast to the more upright and sagittal plane approach adopted during linear sprinting, curvilinear sprinting requires the generation of centripetal and medial-lateral (ML) GRF through a medial whole-body lean to help counteract a rotating moment and permit the continuation of a curved path of travel (25,26,91). For example, different hip and knee kinematics, foot placement and shank angle, and greater lower-limb ROM (26), have all been observed during curved sprinting compared to linear sprinting (7,25,26,37,91). Specifically, the inside leg has been described as a frontal plane stabiliser (7,37), with the lower-limb displaying greater adductor and semitendinosus muscle activation (65), alongside greater lower-limb ROM within longer GCT, compared to the outside leg and normal linear sprinting (26,65). The inside leg also displays greater hip adduction, hip flexion, and hip external rotation, alongside greater ankle eversion (i.e., ankle-eversion strategy), in comparison to the outside leg and linear sprinting (7,37,39). This posture commutatively lowers the COM, facilitating an inclination of the inside leg and medial body lean towards the curvature to assist in centripetal acceleration (7,25,26,37,39,91,179).

Conversely, the outside leg has been suggested to play a more important role in terms of propulsion and rotation (7,37,40,179), with greater hip and knee internal rotation, combined with greater gluteus medius and biceps femoris muscle activity in comparison to the inside limb (26,37,40,65,91,180). Typically, this will result in an asymmetrical GRF profile between limbs, as greater ML GRFs over shorter GCT are observed in the outside limb (26,37,40,65,91,180). Interestingly, it is has been suggested that the GSA complex is pivotal to managing the centripetal forces during curvilinear sprinting and may be the performance-limiting factor through the generation of plantarflexion moments (118). With curvilinear sprinting drawing more similarities between linear sprinting, opposed to COD, perhaps strengthening the mechanical characteristics of the ankle complex may translate to performance improvements in both qualities of MDS; however, future investigations are needed to further examine this speculation.

Insert Table 1 near here

From a kinematic and spatial-temporal perspective, lower velocities have been observed with curvilinear sprinting (e.g., 1 – 15 m radii) compared to linear sprinting (25,26,37,65,91,180). Shorter stride cycle times, reduced SL, and slightly greater SF are required to maintain balance and posture during travel, with these differences amplified with increased sprinting curvature (25,26,37,65,91,180). Additionally, subtle differences in step length and frequency have been observed between inside and outside limbs during curved sprinting (e.g., 1 – 6 m radii), with the inside limb typically displaying greater SF and shorter SL compared to the outside limb (37). Reduced FTs have been reported during curved sprints (5 m radius), which contributes to the shorter stride cycle times (179). Thus, in combination with the increased step and stride frequencies associated with curved sprinting, this increases the time in contact with the ground for force application and centripetal acceleration (37,179). Additionally, the reduced FTs ensure that the athlete does not further deviate from the curvilinear path of travel because greater airtime results in greater travel of the COM along a path tangential to the curve, which is sub-optimal for curved sprinting (179). It should be noted that the kinetic, kinematic, and spatiotemporal differences between limbs, and compared to linear sprinting, are largely influenced and dependent on the curvature (radius) of the sprint (25,26,37,91,180). Nonetheless, because of the importance of curved sprinting actions in soccer (19,24–26,31,67), and the distinct biomechanical differences between curved and linear sprinting (7,25,26,37,39,40,65,91,179,192), it is essential that curved sprinting is assessed and trained as an independent athletic quality, and practitioners are encouraged to design MDS programmes in accordance with the movement characteristics that are specific to the sport.

Agility & Contextual Speed

Agility can be broadly defined as a "rapid whole-body movement with change of velocity or direction in response to a stimulus" (176). An agility action is, therefore, predicated on a perceptual and decision-making process in response to a stimulus, of which the subsequent outcome is a positive or negative change in acceleration, or a COD manoeuvre (176). These decision-making processes require perceptual-cognitive factors (i.e., visual scanning, knowledge of situations, pattern recognition, anticipation) to be coupled with a motor response which will produce a whole-body movement (176). As such, although the aforementioned pre-planned qualities (i.e., acceleration, deceleration, COD and curvilinear speed) discussed in this text are considered essential elements to develop within a soccer strength and conditioning programme, it is the interaction of perceptive, cognitive and motor control capabilities with the ability to apply effective movement that wholly contributes to MDS performance (93–95,210).

Insert Figure 3 around here

Specifically, from a soccer perspective, agility may explain the ability to move effectively in the context of a soccer match. The performance of soccer-specific skills require the athlete to move towards these specific actions through a perception-action coupling in relation to the constantly changing scenarios on the pitch (95). Therefore, athletes need to be able to recognise and exploit game scenarios in order to utilise efficient movement skills to apply their velocity capacities. This has brought about the development of the 'gamespeed' concept, which refers to the ability to exploit the qualities of speed and agility within the context of a soccer match (95). Such an approach requires a blend of skill-related technical and tactical elements of the game to improve sport-specific movement (94). This concept, therefore, should not only be specific to the team sport in question, but should also be specific to the soccer team itself, as a means of developing key movements in relation to underpinning technical and tactical principles that guide the club's coaching philosophy. Thus, establishing a club's game model (50) is recommended in order to effectively scaffold a club's coaching philosophy upon the development framework of a MDS programme (Figure 3). For practitioners embedded within clubs, this may be achieved through communication with the technical coaching staff to harmonise the themes of soccer skill coaching with the aims of physical training blocks. For a more detailed outline of how such an approach is developed and applied within a soccer academy context, readers are referred to an excellent introductory article by Jeffreys et al. (95).

With that said, however, the development of agility is a controversial area, especially in the context of youth athletes. Predominantly, research has investigated the maturational and training-induced changes in strength, SSC function, sprinting and jumping ability (111,113,152,162,170,171). Research regarding growth, maturation and COD performance in youth athletes is lacking (58), and even less is known with regards to agility, which is a task of much greater complexity (114). The underlying issue being it is difficult to evaluate 'agility' performance, and subsequently monitor the effectiveness of MDS training programmes, because it is very difficult to administer a standardised, reliable, sport-specific agility test (149,211). Therefore, working in cohesion with the technical coaching staff may be an effective means of developing sports-specific agility (i.e., gamespeed or contextual speed) that may have a positive effect and translate to performance on the pitch from physical, technical and tactical perspectives.

With that said, the authors advise caution regarding an approach towards early sports specialisation in youth athletes, in particular within the context of agility development, which should, arguably, be emphasised during the transition to senior training (i.e., late-adolescence and early adulthood), where there can a be greater emphasis on sports-specificity and tactical training. Certainly, within the early years of development (i.e., < 13 years of age), an emphasis should be placed on developing general agility skills through a diversified, multi-lateral approach (112,195,208). Diversifying the youth athlete’s exposures to games and scenarios which emphasise different movements, tactical dimensions, and patterns of play in attacking and defensive situations, can be achieved through agility games (e.g., tag, evasion, partner follow, agility races) and the sampling of a variety of different sports (e.g., rugby, basketball, hockey, and American football) (129). Given the high-intensity nature that is inherent with MDS training, this approach will increase the young athlete’s movement variability and subsequently provide a more balanced distribution of stress to greater range of anatomical structures by altering the point of force attenuation or production, thus potentially reducing the risk of overuse injury (163,164). This training methodology may be used as a means of promoting athletic skills development, fostering creativity and intuition and reducing the risk of injuries, which will provide the youth soccer player with an expansive foundation of movement skills for when the time comes to transition to the senior game.

Conclusion

In this review article, the authors have defined MDS and explored the scientific underpinnings of each of its components in relation to performance and injury risk in soccer. In order to optimise the development of MDS, it is critical to understand its theoretical underpinnings to appreciate how each MDS quality has its own unique implications for performance and injury risk. Ultimately, effective MDS performance in the context of soccer is underpinned by a perceptual-action (perceptual-cognitive component) response to dynamic, ever-changing scenarios within a game. It cannot be dismissed, however, that enhancing an athlete’s physical and mechanical ability to accelerate, decelerate, COD, and attain top-end speeds both linearly and curvilinearly, will positively enhance ‘agility’ and ‘game-speed’ soccer performance. Fundamentally, the underpinning philosophy regarding the preparation of soccer players should be to generate robust and effective 360˚ athletes, who have the competency to accelerate, decelerate, and change direction rapidly and effectively from both limbs. Harmonising sporting skill with speed development is, therefore, pivotal to sporting performance. Thus, although each quality can be isolated and trained as such, an optimal programme should always seek to combine and develop the two in concert.

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