CHAPTER 37

Speed and agility training

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Introduction

Natural play activities in children are characterized by fundamental movement skills that include agility and speed, which are also determinants of success in youth sport.[1–3] It has also been suggested that speed and agility may be important components of health-related fitness, with some limited evidence suggesting they may be an important marker of bone health.[4–6] As a result, sprint and agility tests have become both popular assessments in youth sport[3,7–10] as well as components of health-related fitness test batteries for children and adolescents.[4,6] While linear sprinting and agility both require the ability to move at speed it has been shown that they each represent independent locomotor qualities in youth athletes.[11] Therefore, it is pertinent to consider speed and agility as separate entities.

Sprinting is a linear skill, with an individual propelling themselves forward as rapidly as possible. A sprint can be divided into four phases; first step quickness, acceleration, maximal speed, and deceleration.[12] Typically, measurements in youth have considered acceleration and speed. Although acceleration and maximal speed (hereafter referred to as speed) are related to one another, they are not the same.[10,13] Time taken to cover the first 10 m of a sprint is often used as a measure of acceleration, which incorporates first step quickness (0–5 m).[12] Speed is normally measured over longer distances of 30–40 m, often with the split times recorded from 10 m onwards to remove the acceleration phase, although the actual point of transition from acceleration to maximal speed will vary between individuals and across populations.[12] In a large sample of 11- to 16-year-old boys it has been shown that maximal speed in a single stride occurs between 15 and 30 m.[14] This chapter discusses the natural development and trainability of speed and agility in children and adolescents.

Until the last decade agility had largely been considered as the ability to rapidly change direction.[15] More recently the definition of agility has been extended to incorporate that rapid changes of direction occur in response to a stimulus.[16] Consequently, agility has both a physical perspective reflecting change-of-direction-speed and a cognitive perspective reflecting perceptual and decision-making skills. Given the difficulty of measuring perceptual skills in context-specific scenarios, most (if not all) of the literature about research in this area with regard to children and adolescents has assessed change-of-direction-speed rather than agility, per se.[3,7–10] Our current understanding of the development and trainability of agility to the physical determinants of change-of-direction-speed are therefore limited, although evidence of perceptual development from the broader literature is available.

Speed

Sprinting is considered a fundamental movement skill (FMS) that is important for both free-play activities and sport participation. Speed can be a distinguishing and desirable physical characteristic, and is also known to be a determinant of success in youth sports, distinguishing between playing levels and age groups in sports such as football,[8] rugby league,[17] and basketball.[9] Consequently, talent identification in youth sports will often include measures of speed as key performance indicators.[3,17,18] This may be problematic; although speed is associated with sports performance it is influenced by age, maturation, and growth. For instance, it has been suggested that peak rates of improvements in speed occur around the time of peak height velocity (PHV),[19] and that these gains will be influenced by changes in body mass and lower limb length,[20] as well as qualitative changes in muscle-tendon structure and function that accompany maturation.[21] It has also been suggested that these developmental processes may influence the responsiveness to speed training throughout childhood and adolescence.[22]

Natural development of speed

Given that sprinting is a key FMS[1] and can be a determinant of success in adult[7,23] and youth sports,[2,3] it is surprising that relatively few studies describe the natural development of sprint speed during childhood and adolescence. Previous large-cohort studies have used plate tapping and shuttle run tests as a form of speed assessment,[24,25] with only a few studies directly examining sprint speed.[14,26] It has been suggested that both boys and girls exhibit similar sprint speed in the first decade of life,[27,28] with both sexes experiencing more rapid natural gains in speed between the ages of 5–9 years; this phenomenon has been termed the 'preadolescent spurt'.[29] A second 'adolescent spurt' occurs with maturation, with peak gains coinciding with puberty[27] and the timing of peak PHV.[14,19] However, it has also been suggested that this spurt in speed development occurs in the early phase of the growth spurt.[30] With maturation, sex differences in speed become more apparent. From the age of 12 years the rate of progression of speed development is dramatically reduced in females when compared to males.[31] It has been suggested that the arrival of the fourth puberty stage (interested readers are referred to Chapter 1 for an analysis of the assessment of biological maturity) marks the end of maximal speed development in girls not involved in sport. [32] Natural speed development, on the other hand, continues into full maturity in males.[29] This disparity between the sexes is attributed to maturational changes in circulating androgens, body dimensions, and body composition.[21,24,29,33]

Development of sprint speed in boys and girls between the ages of 9 and 15 years is shown in Figure 37.2. It is clear that improvements in speed are observed across the age range for all percentiles in boys, and most percentiles in girls. For a given percentile boys are always faster than girls, but the relative difference between the sexes changes with age. Girls demonstrate a more rapid rate of speed development up until the age of 12 years, whereas boys demonstrate a more rapid rate of speed development from the age of 12 years onwards. The differential timing of periods of rapid development when comparing the sexes supports a maturational effect on speed development. The timing of rapid speed development shown in Figure 37.1, which is based on data from Catley and Tomkinson,[34] occurs prior to the expected age of PHV in the population. This observation supports the longitudinal monitoring of speed in a small cohort of boys and girls, where peak gains in speed occurred prior to PHV.[30] In another longitudinal study of a small sample of boys, peak gains in speed were suggested to occur around the timing of PHV; according to Philippaerts *et al.*,[19] participants actually became slower in the 18 months prior to PHV, and the subsequent increase in speed may simply have reflected a long-term correction to speed.[35] The observation that some youths become slower around the onset of the growth spurt has been attributed to adolescent awkwardness and temporarily disrupted co-ordination during periods of rapid limb growth.[19,24] When comparing boys of different maturity status, Rumpf and colleagues[36] found that maximal speed could be largely explained by power and horizontal force in both pre- and post-PHV boys. However, this was not the case for boys circa PHV, which again may have been related to this group experiencing some level of awkwardness. Increases in maximal running speed in boys of advancing age have been shown to disappear when data are adjusted for somatic maturity,[2,36] confirming that speed gains are maturation dependent. From cross-sectional examination of a large cohort of 11- to 16-year-old boys, data show that speed remains relatively stable from approximately 3 years to 1 year prior to PHV, with significant gains in speed observed from the timing of PHV onwards.[14] While there is clearly an influence of maturation on speed development, it is not entirely clear whether peak gains in speed coincide with the timing of PHV, or the start of the growth spurt.

It is difficult to understand the mechanisms that underpin the natural development of speed during different stages of growth and maturation, given the contribution and integration of a number of different factors. These include quantitative changes in body size, muscle cross-sectional area and length, biological and metabolic changes, morphological alterations to the muscle and tendon, and neural/motor development as well as biomechanical and co-ordination factors[21] (interested readers are referred to Chapter 3 and Chapter 4 for a discussion of motor development and biomechanical coordination). There is a suggested link between the observed preadolescent spurt in sprint speed and the development of the central nervous system and improved co-ordination.[27,29] This theory is supported by the rapid growth of the central nervous system during the first 7 years of life,[28] the peak maturation of brain regions which control movement (at 7.5 years and 10 years of age in girls and boys, respectively),[37] and the observation that mature stride dynamics are achieved somewhere between the ages of 7 and 11–14 years of age.[31,38]

Changes in height, leg length, and muscle size during adolescence support a maturational influence on speed development, although Butterfield *et al.*[33] found no association between longitudinal growth rates of height and weight and improved running speed in children aged 11–13 years. Metabolic factors can influence maximal sprint speed, and it may be that immature children have lower muscle phosphocreatine (PCr) stores,[39] although children and adults have been shown to break down adenosine triphosphate (ATP) and PCr at similar rates.[40] Maturation of the glycolytic system is likely to be more pronounced, but this would likely have more of an effect on prolonged high-intensity running, rather than maximal speed. Maturation of muscle-tendon architecture and inherent characteristics are likely to have a substantial influence on the development of sprint speed. Ovalle[41] reported marked increases in the surface area of the muscle-tendon junction from childhood into adulthood; this change was accompanied by a reduced number of Golgi organs in the mature state. Partly as a consequence of these changes in the biomechanical properties of muscle and connective tissue, a tenfold increase in muscle-tendon stiffness has been observed in the first two decades of life.[42] Changes in muscle stiffness will also be influenced by neural factors, with firing rates,[31] twitch times,[42]

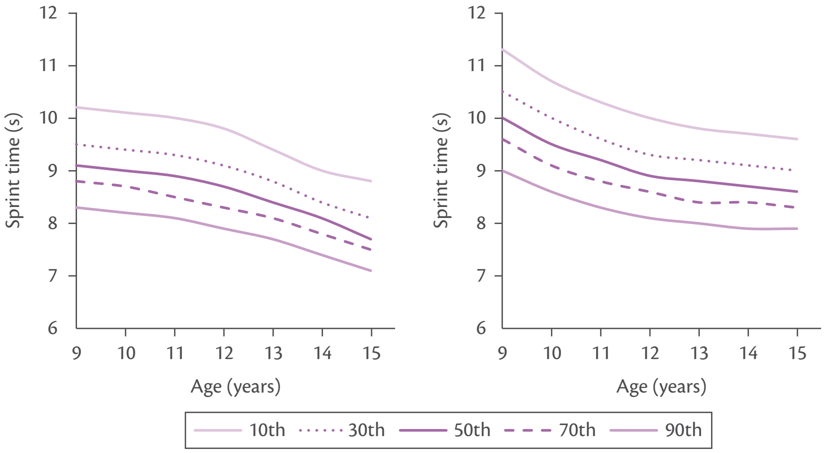

Figure 37.1 Fifty-metre sprint time percentiles in 9- to 15-year-old Australian boys and girls. Boys on the left and girls on the right.

Data from Catley MJ, Tomkinson GR. Normative health-related fitness values for children: analysis of 85347 test results on 9–17-year-old Australians since 1985. Br J Sports Med. 2013; 47: 98–108.

preactivation,[43,44] reflex muscle activity,[45,41] and coactivation[42,46] all shown to develop through childhood in a manner that would favour increased speed production. Greater muscle-tendon and leg stiffness will theoretically enhance sprint performance by enabling the lower limbs to resist large vertical displacement of the centre of mass as well as increasing rate of force development during ground contact.[47] Leg stiffness has been shown to be a predictor of maximal sprint speed in adolescent boys.[48] When examining sprint speed on a non-motorized treadmill, Rumpf *et al.*[49] noted that maximal speed, relative vertical stiffness, and relative leg stiffness all increased from pre-, to circa-, to post-PHV in boys; however, these differences disappeared when maturation was statistically controlled. These findings support a role of maturation and stiffness in the development of sprint speed.

Growth, maturation, and spatio-temporal determinants of speed

Running speed is a product of stride frequency and length.[50] Stride frequency is a function of ground contact time and flight time and stride length is determined by a combination of the distance covered while in contact with the ground and the distance covered while in flight. Understanding these spatio-temporal determinants of speed can help provide insight into the process of speed development in children and adolescents. In an early study Schepens *et al.*[26] examined the sprint mechanics of 2- to 16-year-old youths, concluding that step frequency changes little with age and that age-related changes in maximal speed are almost entirely due to proportional increases in stride length. However, a trend for decreasing step frequency was apparent in the data and the lack of a statistically significant change was likely due to the small sample sizes in each group (n = 6–8). Recently Meyers *et al.*[14] examined spatio-temporal determinants of speed in a large cohort of circa-adolescent boys (n = 336). The authors reported significant decreases in stride frequency across boys classified from approximately 3- to 1-year prior to PHV; during this time, stride length significantly increased and there was no net change in speed. Stride frequency then stabilized in boys around PHV and 1 year post-PHV, while continued gains in stride length in these boys resulted in increased maximal speed. Similar to Schepens *et al*,[26] Meyers *et al.*[14] concluded that increased stride length is the primary determinant of maximal speed, as this variable explained 57% of the reported variance. This contrasts with adult data, with data showing faster runners achieving longer strides through greater application of ground reaction forces during a reduced ground-contact period.[51,52] In comparison, paediatric data suggest that through adolescence children increase ground-contact times, which reduces stride frequency; however, this is more than compensated for by relatively larger increases in stride length. It is also worth noting that flight times remain unchanged with maturation,[14] which is consistent with comparisons of adult sprinters of different abilities.[51,52]

A recent study by Meyers *et al.*[20] demonstrated that spatio-temporal determinants of speed are maturity dependent. In boys pre-PHV, stride frequency accounted for the greatest amount of variability (58%) in maximal speed, whereas in boys circa- and post-PHV, stride length explained the greatest amount of variance (54%) in speed. In elite adult sprinters it has been suggested that those with lower levels of strength are more stride-*frequency* reliant and those with greater strength levels are more stride-*length* reliant.[53] This theory can be applied to the development of speed; immature children with lower muscle mass and lower strength, but who have a well-developed somatic nervous system, appear to be more reliant on a quick turnover of their legs to generate speed. Conversely, maturation-related improvements in strength and power output observed around the time of PHV[54,55] result in an ability to generate large relative forces and a shift to where adolescents become more stride length reliant when generating speed. Indeed, when comparing maximal sprinting in boys pre-, circa- and post-PHV, data show that relative force production increases alongside stride length and speed.[36] This suggests that with the onset of maturation, increases in mass, muscle size, and relative strength allow adolescents to become more stride-length reliant when generating speed.

Physical growth also influences speed development. Data suggest that increasing body mass as a result of maturation is related to increased contact times that reduce stride frequency.[14,20] However, both greater relative levels of strength[36] and increases in stature and leg length may compensate for this, and increased leg length with advancing maturation has been shown to influence sprint performance,[2,19,20,26] with recent research reporting a correlation of $r = 0.60$ ($p < 0.01$) between leg length and stride length at maximal speed in 11- to 15-year-old boys.[14] A longer leg may allow for a greater distance to be covered while in contact with the ground; this has been suggested in adult sprinters.[51] The role of increasing limb length would support a developmental spurt in speed during the early phase of the growth spurt, when long bones of the body are experiencing rapid growth. It should be noted that our understanding of the development of spatio-temporal determinants of speed is limited to research with boys.

Speed training

There has been debate over recent years regarding how age and maturation interact with training responsiveness in children and adults. The 'trigger hypothesis'[56] suggests children do not respond to training until after the onset of puberty. Similarly, a popular coaching model suggests that 'windows of opportunity' exist when training gains in speed are maximized at specific ages in boys and girls, and that a failure to fully utilize those windows will limit future potential.[57] However, this belief has been strongly refuted due to a lack of supporting empirical evidence.[21,58] More recently, it has been suggested that training-induced gains in sprint speed can be made throughout childhood and adolescence, although the mechanisms that underpin those gains, as well as the types of training that are most effective, might differ with maturation.[1,22]

Short-term speed training interventions

Sprint speed can be improved through a variety of training modes, including sprint training, technical training, strength training, and plyometric training. Sprint training involves participants completing maximal sprint efforts, which can be modified to include various forms of both resisted (e.g. sled towing) and assisted (e.g. downhill) training. Given that specificity is a key principle of training it is surprising that few studies have focused on the efficacy of free, resisted, or assisted sprint training to improve speed in youths.[22] Likewise, a recent systematic review highlighted that only a handful of free, resisted, and assisted sprint training studies have been done in adults.[59] While training interventions to improve speed may employ some sprint work, they typically involve either plyometric or strength training, or a combination of these. Table 37.1 provides an overview of sprint training studies in boys and highlights the

Table 37.1 An overview of training studies that have assessed maximal sprint speed in boys aged 10–17-years-old.

Reference	Age	Mode	Total sessions	Test distance(s)	% Change
Rumpf *et al.*[62]	10.4 ± 0.8	Res Sprint	16	0–30	1.0
Venturelli *et al.*[63]	11.0 ± 0.5	Sprint	24	0–20	2.4
Venturelli *et al.*[63]	11.0 ± 0.5	Combined	24	0–20	2.2
Kotzamanidis[64]	11.1 ± 0.5	Sprint	20	10–20	5.5
Kotzamanidis[65]	11.1 ± 0.5	Plyometric	10	10–20	3.5
Pettersen and Mathisen[66]	11.5 ± 0.3	Sprint	6	0–20	1.8
Chelly *et al.*[67]	11.7 ± 1.0	Plyometric	30	Vmax	3.7
Ingle *et al.*[68]	11.8 ± 0.4	Combined	36	0–40	3.2
Diallo *et al.*[69]	12.3 ± 0.4	Plyometric	30	0–20	2.8
Wong *et al.*[70]	13.5 ± 0.7	Strength	24	0–30	2.3
Chaouachi *et al.*[71]	13.3 ± 0.7	Combined	24	0–30	2.8
Chaouachi *et al.*[71]	13.7 ± 0.8	Plyometric	24	0–30	3.4
Christou *et al.*[60]	13.8 ± 0.4	Strength	32	0–30	2.6
Rumpf *et al.*[62]	15.2 ± 1.6	Res Sprint	16	0–30	5.8
Coutts *et al.*[72]	16.6 ± 1.2	Strength	18–36	0–20	≤0.9
Chelly *et al.*[73]	17.0 ± 0.3	Strength	16	35–40	10.9
Kotzamanidis[74]	17.0 ± 1.1	Combined	39	0–30	3.5
Kotzamanidis[74]	17.1 ± 1.1	Strength	39	0–30	0.5
Thomas *et al.*[75]	17.3 ± 0.4	Plyometric	12	0–20	≤0.3
Maio Alves *et al.*[76]	17.4 ± 0.6	Combined	6–12	0–15	≤7.0

The dashed lines separate the table in to age groups that approximate to pre- (top), circa- (middle), and post- (bottom) peak height velocity.

A positive % change represents an improvement in sprint performance.

Res Sprint = Resisted Sprint (sled towing), Vmax = maximum velocity.

different forms of training employed across studies; they examined training programmes lasting from 6 to 16 weeks with between one and three training sessions per week. Changes in speed in Table 37.1 are reported for sprint distances ≥15 m, to reflect changes in speed rather than acceleration. All studies report on positive improvements in speed following training. Most studies show the level of improvement as > the level of expected noise (coefficient of variation = 0.83%) reported for 12- to 15-year-olds completing a 30 m sprint.[60] Additionally, training-related gains in performance are generally greater than those that would be expected from growth and maturation. Williams *et al.*[35] have reported that 30-m sprint times improve at a rate of 2.7% per year in 11- to 16-year-old football players, which would equate to gains of approximately 0.3–0.8% over the period of the training studies included in Table 37.1. While there are much fewer data available for girls, the existing research does suggest that girls can also improve their speed with sprint training.[61]

In a systematic review of training studies, Rump *et al.*[22] concluded that plyometric training and combined training are the most effective methods to improve speed for pre- and post-PHV boys, respectively; there were limited data available for boys who were circa-PHV. However, it should be noted those conclusions were based on measures of both acceleration and speed. Additionally, these data are from studies where maturity was not directly classified. The findings of Rumpf *et al.*[22] and the results presented in Table 37.1 support the notion that children and adolescents can be responsive to training. The fact that pre- and post-PHV participants may be more responsive to different types of training has been linked to natural development.[1,22] From studies identified in Table 37.1, boys who would be expected to be in a pre-PHV age range (<13 years old) respond to training that includes a plyometric stimulus, either in isolation or combined with other training. Boys in a post-PHV age range respond most to interventions that include a strength stimulus (either in isolation or combined). These responses may be facilitated by high neural plasticity in immature children and the greater propensity of mature youth to experience hormone-mediated changes in muscle size and architecture, although direct evidence is needed to confirm this. While there are limited data available on boys who are circa-PHV, the evidence from Table 37.1 suggests that boys around the age of PHV (~13.5–14 years old) can make speed gains via a variety of training methods. The similar success across a range of studies and interventions in this age group may be related to the fact that all studies included a reasonable and consistent dosage of two sessions per week, for either 12 or 16 weeks.

Direct investigations of maturation and training interactions

Studies that have directly examined the interaction of age and maturation with training provide further insight into responsiveness.

Rumpf *et al.*[62] compared gains in sprint speed in 10- and 15-year-old boys after 6 weeks of sled tow (resistance) training. While younger boys showed no changes in performance, older boys significantly improved sprint performance, stride frequency, stride length, leg and vertical stiffness, force, and power production. Both groups followed the same training programme pulling loads of between 2.5–10% of body mass. However, data show that when pulling relative loads, pre-PHV children are 50% slower than post-PHV children during resisted sprints.[77] Therefore, it may be that lower levels of strength, excessive resistance, and an immature biological state combined to prevent the younger boys from experiencing any speed gains. In a recent study, Meylan *et al.*[78] reported that pre-PHV boys experienced small gains (2.1%) in sprint speed following 8 weeks of strength training, compared to moderate gains for both circa-PHV (3.6%) and post-PHV (3.1%) boys. Following the intervention, the post-PHV group achieved large gains in strength compared to only small gains in other groups; this suggests that more mature youth may be able to achieve greater gains in force production following strength training.[79]

Lloyd *et al.*[80] examined the influence of maturation and mode of training on speed development, comparing the responses of pre- and post-PHV boys between control, plyometric, strength, and combined (strength and plyometric) training groups. Twenty-metre sprint speed demonstrated small gains in performance for both the pre- and post-PHV groups following either plyometric or combined training, but with no gains in the control or strength training groups. As strength training did transfer benefits to other performance markers, including concentric strength and acceleration (post-PHV only), gains are therefore most likely to be observed when testing is specific to training. Both Lloyd *et al.*[80] and Thomas *et al.*[75] exposed post-PHV boys to plyometric interventions that included two sessions per week for 6 weeks, with both studies exposing participants to a similar volume of ground contacts. While Lloyd *et al.*[80] reported significant gains in speed, Thomas *et al.*[75] noted no change in speed. The disparity in findings between these similar studies can most likely be accounted for by considering the sample characteristics. Lloyd *et al.*[80] recruited a population of previously untrained boys, while Thomas *et al.*[75] examined youth with at least 4 years of football training history. For the latter, the training load of 80–120 ground contacts per session may have been too low given their training history. This may be significant, especially when considering that another plyometric training study with adolescent football players used a training load of 200 contacts per session.[81] However, it should also be noted that a systematic review of plyometric training in youth recommends that volume should not exceed 120 contacts per session to help prevent overuse injuries.[82] Alternatively, Table 37.1 and the work of Lloyd *et al.*[80] suggest that combining strength and plyometric training is an effective way to promote speed development for youth of all ages and maturation. Furthermore, it can provide the variety of training that should be central to any long-term athletic development programme.[1]

Longitudinal monitoring of speed in sporting populations

There is limited research available relating to the effectiveness of long-term, systematic training on speed development in childhood and adolescence. What information does exist comes largely from longitudinal investigations of the development of male youth soccer players. Gravina *et al.*[8] reported that 11- to 14-year-old soccer players who are regularly selected to play improve their sprint time by approximately 5% over the course of a season, compared to improvements of only 1% in reserve players. These findings may reflect the fact that selected players are exposed to a greater training stimulus through more game time, or there may be a likely selection bias towards those experiencing early maturation and rapid gains in speed.[8] Williams *et al.*[35] observed 12–16-year-old boys in a soccer centre of excellence over a 3-year period and found boys improved 30-m sprint times at a rate of 2.7% per year. Vanttinen *et al.*[83] used longitudinal and cross-sectional data to compare the development of 11- to 17-year-old soccer players and controls. While soccer players were faster than controls in each age group, the rate of improvement in 30-m sprint performance was similar in both cohorts, with improvements of approximately 19% over the 6-year period. In another study of young soccer players, academy players were found to improve 30-m sprint times significantly more than controls over a 3-year period (~9% versus ~4%).[84] Sander *et al.*[85] examined the influence of strength training in youth soccer players, comparing 13-, 15-, and 17-year-old players. Players were split into a control group, and a strength-training programme group for a 2-year period. Strength-training groups routinely made gains in speed significantly greater than controls, and the magnitude of gains decreased with advancing age; 30 m sprint times in the strength-training groups improved by 5.8% in the youngest group, 4.6% in the 15-year-olds, and 1.5% in the oldest group. Therefore, it appears that systematic long-term training in a soccer academy setting can promote enhanced speed development. However, although sometimes significant, the magnitude of the difference between gains in experimental and control groups in longitudinal studies is relatively modest;[83–85] similar gains have been observed in intervention studies of much shorter terms.[64,73] To the authors' knowledge, no long-term training studies have been specifically designed to improve maximal speed in children and adolescents.

Agility

Previously accepted definitions of agility suggested the ability to 'change direction rapidly';[15] however, it is now accepted that this paints an overly simplistic view of what is an intricate, multifactorial physical quality.[16] Regardless of the setting, movement occurs in response to external stimuli, e.g. an obstacle or an opposition player. Therefore, the more recent definition describes agility as rapid, whole-body movements that require the changing of direction, velocity, or both, in response to a stimulus.[16] Figure 37.2 (adapted from Sheppard and Young[16]) provides a schematic representation of the change-of-direction-speed and perceptual and decision-making skill sub-components of agility. This definition better represents true agility performance, and recognizes both *change-of-direction-speed* and *perceptual and decision-making processes*, and the multi-factorial nature of each component. For example, a child performing an agility-based movement will i) initially observe their external environment, ii) process relevant cues, and then iii) recruit and employ the relevant motor control strategy in response to the task. Therefore, while change-of-direction-speed variables (e.g. technique, sprinting ability, leg muscle qualities, and anthropometry) will ultimately affect the witnessed movement output, these cannot be used without first receiving and interpreting external stimuli. This process is further confounded by the manner in which children learn and perform motor skills. How a combined interaction of individual constraints, environmental constraints, and task constraints influences motor skill development has been thoroughly examined.[86] Therefore, it should be noted that the perfect agility technique does not exist, as the child will invariable modify their technique based on the interaction between individual (e.g. height), task (e.g. degree of challenge), and environmental (e.g. floor surface) constraints.

Agility is a key FMS,[87] which children need in order to maintain adequate physical fitness later in life.[88] Agility is also recognized as an integral component of successful sports performance, and research highlights its importance for success in multidirectional, intermittent invasion sports such as lacrosse,[89] basketball,[90] and soccer.[91] Furthermore, it has been shown that agility performance can differentiate between elite and novice player status across a range of sports.[17,92,93] Yet, despite the obvious importance of agility to general health and sports performance, it remains one of the most under-researched physical fitness components within the paediatric literature.[94]

Testing agility

As both change-of-direction-speed and perceptual and decision-making skills comprise true agility performance, it becomes evident that a number of existing protocols used to test agility instead test change-of-direction-speed. Examples previously used within paediatric research include the quadrant jump test,[95] 5 × 10 m test,[19] the zigzag test,[9] Balsom agility test,[96] 10 × 5 m test,[18] line drill, T-test,[97] and the 5-0-5 agility test.[75] All of these test protocols involve pre-planned movements and do not necessitate responding to an external stimulus, which is the true discerning quality of agility. This has connotations for our understanding of both the way in which agility performance develops naturally as a result of growth and maturation, as well as how, as a physical quality, it can be augmented with relevant training interventions.

Natural development of agility

Minimal literature exists that explores the way in which growth and maturation interact with the development of agility. Consequently, how and why agility performance changes as a result of the unique developmental processes associated with both childhood and adolescence remain unclear. Due to both the existing limitations within the

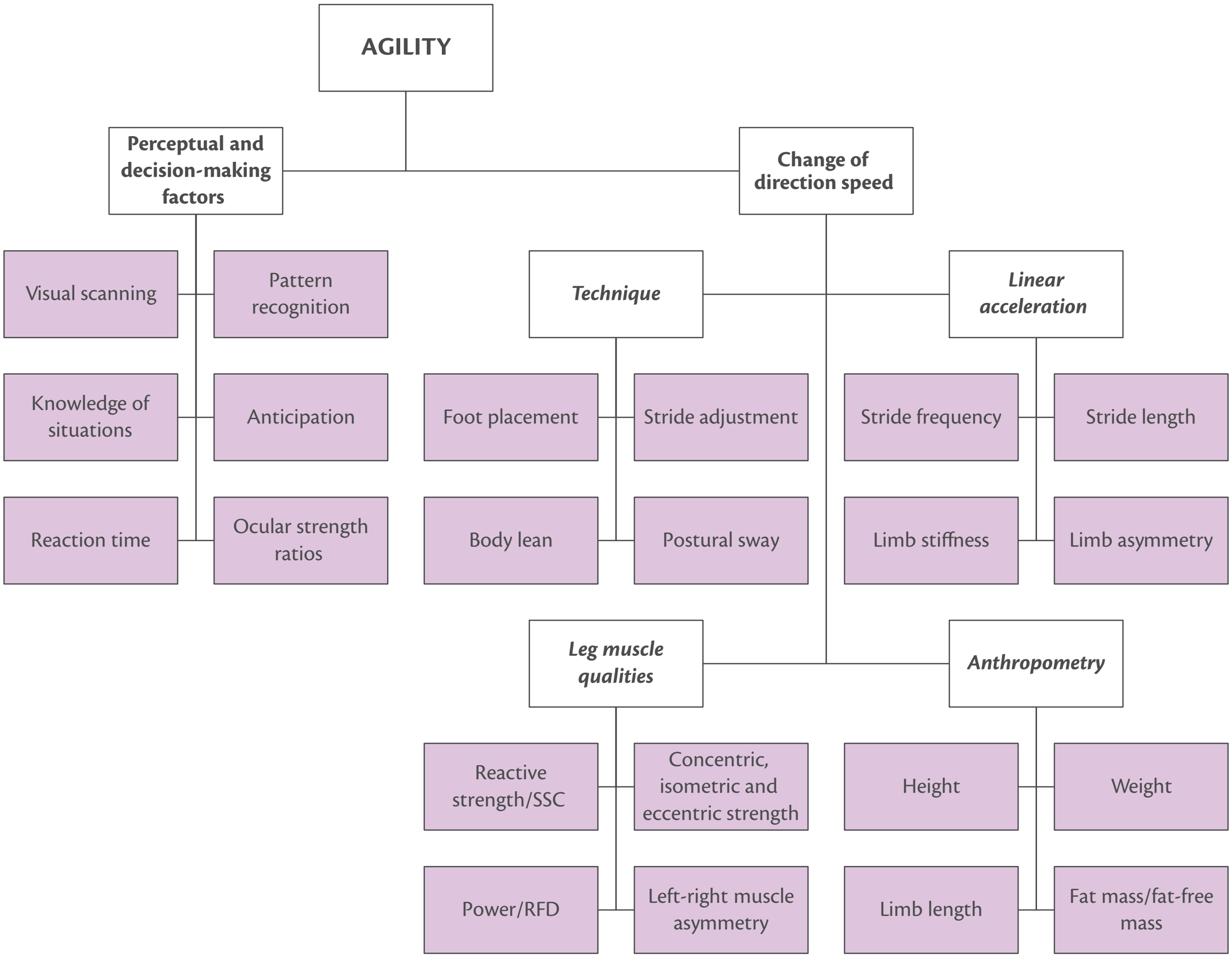

Figure 37.2 Components of agility performance.

Adapted from Sheppard JM, Young WB. Agility literature review: classifications, training and testing. J Sports Sci. 2006; 24: 919–932.

agility development literature and the multifactorial nature of agility performance, we must examine how both change-of-direction-speed and perceptual and decision-making skills develop independently.[94]

Change-of-direction-speed

Small amounts of existing longitudinal data, as well as some cross-sectional studies, show that change-of-direction-speed develops naturally in a non-linear fashion throughout childhood and adolescence.[83,95,98] Research also shows that sex differences only become apparent at the onset of puberty. Specifically, Eisenmann and Malina[95] studied change-of-direction-speed performance in the quadrant jump test in a sample of boys and girls over a 5-year period (Figure 37.3). Their data showed that prepubertal boys and girls performed similarly in the quadrant jump test, although sex-associated differences were apparent during the adolescent growth spurt. Notably, during puberty and into late adolescence boys, continued to improve change-of-direction-speed performance, while girls' rate of improvement plateaued. The influence of puberty on change-of-direction-speed has also been highlighted in more recent research. Jakovljevic *et al.*[9] showed that change-of-direction-speed, as measured by performance in the zigzag test, was significantly better in 14-year-old boys than in 12-year-old boys, while Philippaerts *et al.*[19] revealed that the greatest rate of change in the 5 × 10 m test occurred approximately around the time of PHV. Similarly, a group of regional male youth soccer players were routinely tested on the eight figure test over a 2-year period. Data showed that the greatest relative improvement in change-of-direction-speed was evident in those boys who transitioned from 13 to 14 years of age.[83] Cumulatively, these data suggest that natural development of change-of-direction-speed: i) is better in adolescents than children, ii) occurs in a non-linear fashion, and iii) is similar in both girls and boys prior to puberty, but sex differences emerge as a result of the adolescent growth spurt.

While the determinants of natural development of change-of-direction-speed remain unclear, an understanding of the determinants of change-of-direction-speed performance (Figure 37.2) and key physiological principles of paediatric exercise science may help explain potential age- and maturity-related changes in performance. Sheppard and Young[16] highlight that *anthropometrics* are potentially an influencing factor in change-of-direction-speed performance. While very little is known about the influence of limb lengths, centre-of-mass orientation, and the ratio of fat mass versus fat-free mass on change-of-direction-speed in youth, intuitively, when comparing two individuals of the same maturity status, the individual with shorter relative limb length, lower centre of gravity, lower levels of fat mass, and higher amounts of fat-free mass would be expected to outperform a taller, fatter, and less muscled peer. While an increase in limb length will likely increase speed into, and out of, a change-of-direction task, greater limb lengths will also increase the height of centre of mass, which makes changing direction more challenging. Conceivably, the positive effect of increased limb length in combination with greater force production from natural increases in muscle mass will likely offset any detrimental effects of an increase in height of centre-of-mass on change-of-direction-speed performance.

More significantly, leg muscle qualities have also been associated with successful change-of-direction-speed performance.[16] Children and adolescents require appropriate levels of concentric, isometric, and eccentric strength to effectively decelerate, transition, and reaccelerate respectively. Increased relative muscular strength and power, as well as a more effective utilization of the stretch-shortening cycle action ultimately enables the child or adolescent to attenuate and produce greater forces and rates-of-force-development during the act of changing direction. Recent research emphasizes the importance of muscular strength for effective change-of-direction performance, especially when strength is normalized to body mass.[99–101] The importance of relative strength and power for effective change-of-direction-speed performance, combined with underpinning paediatric muscle physiology, to some degree, helps explain the natural development of change-of-direction speed in youth. Prepubertal boys and girls perform similarly in change-of-direction-speed tasks,[95] which mirrors the comparatively similar linear development of muscle strength in both boys and girls during childhood.[102] Noticeable improvements in change-of-direction-speed are evident as children reach the onset of puberty and experience the adolescent growth spurt, which is commensurate with the concomitant non-linear gains in muscle strength.[103] During adolescence, males experience accelerated gains in muscle strength, while females are less likely to experience on-going improvements.[104] This likely explains the associated sex differences witnessed in change-of-direction-speed following the adolescent growth spurt.[95]

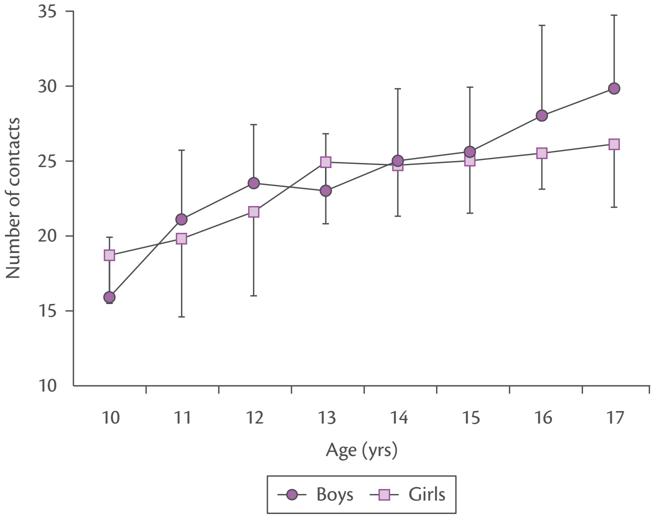

Figure 37.3 Development of change-of-direction-speed as measured from the quadrant jump test in boys and girls, the test measures the number of valid contacts made in 10 s.

Data from Eisenmann JC, Malina RM. Age- and sex-associated variation in neuromuscular capacities of adolescent distance runners. J Sports Sci. 2003; 21: 551–557.

Perceptual and decision-making processes

Within the agility literature, there is a lack of empirical research examining the natural development of perceptual and decision-making processes during childhood and adolescence. Thus it remains unclear how growth and maturation interact upon the development of these vital sub-components of agility performance. However, developmental motor control literature has shown that childhood is an opportune time to develop cognitive processes because of the heightened neural plasticity associated with childhood.[105,106] Specifically, strengthening of synaptic pathways,[107] further neural myelination,[108] and the process of synaptic pruning[109] all mediate faster stimulus-response times and overall increased cognitive capacity in children. Therefore, theoretically, while greater maturity-related natural developments in force-producing capacity would be expected in adolescents compared to children, the age-related plasticity of neural pathways may lead to more adaptable perceptual and decision-making processes in children when compared to adolescents. However, it should be noted that further research is required to validate this speculative theory.

Agility training

Effect of targeted training on change-of-direction-speed

While there is now a compelling body of evidence supporting the trainability of physical qualities including strength, power, speed, and endurance in youth, research examining the trainability of agility performance remains scarce. Owing to the limitations surrounding the various definitions and testing modalities for agility, previous studies that have attempted to monitor training-induced changes in agility have rather typically only examined the effects of training on change-of-direction-speed. Within the literature, a range of short-term training interventions have proven successful in augmenting positive changes in change-of-direction-speed performance in youth, including strength training,[110,111] plyometric training,[75,112,113] combined training,[96,114] change-of-direction sprints,[115] and small-sided games.[115,116] Typically, the duration of these interventions has ranged from as little as 3 weeks up to 16 weeks. Therefore, little is known about the long-term effects of training on change-of-direction speed ability. Of the available evidence, Keiner *et al.*[117] recently examined the effects of a 2-year strength training intervention on change-of-direction-speed performance in young soccer players. The study showed that under 15, under 17, and under 19 players all made significant improvements in change-of-direction-speed following exposure to the training programme. Interestingly, changes in change-of-direction-speed performance showed moderate to strong correlations with changes in relative strength levels (as determined by one repetition maximum front and back squats). This latter finding highlights the relative importance of force-producing capacities for successful performance in change-of-direction tasks. Table 37.2 provides a summary of the training interventions targeted towards enhancing change-of-direction-speed performance, and shows that improvements in change-of-direction can be achieved through a variety of training means. However, the majority of studies examined adaptations in adolescents, and thus there is a lack of research examining training effects in immature, prepubertal youth. Similarly, there is a lack of data relating to the responsiveness of change-of-direction-speed to training in girls.

Effect of targeted training on perceptual and decision-making processes

Very little research exists into the trainability of perceptual and decision-making determinants of agility performance, especially in paediatric populations. Therefore, the manner in which

Table 37.2 Summary of training studies targeting change-of-direction-speed in boys aged 12–17 years old.

Reference	Age	Duration	Test	Mode	% Change
Söhnlein *et al.*[113]	12.3 ± 0.8	16 weeks	Hurdle agility test	Control	0.5
	13.0 ± 0.9			Plyometric	6.0
Meylan and Malatesta[112]	13.1 ± 0.6 13.3 ± 0.6	8 weeks	10 m zigzag agility test	Control Plyometric	−2.8 9.6
Faigenbaum *et al.*[114]	13.4 ± 0.9 13.6 ± 0.7	6 weeks	Pro-agility test	Combined Resistance	3.8 0.3
Gabbett *et al.*[111]	14.1	10 weeks	5-0-5 agility test	Strength/RSA	2.1
Chaouachi *et al.*[115]	14.2 ± 0.9	6 weeks	Zigzag test	SSG COD Control	2.5 5.0 2.6
Garcia-Pinillos *et al.*[96]	15.5 ± 1.3 16.4 ± 1.5	12 weeks	Balsom agility test	Contrast Control	5.1 0.3
Gabbett *et al.*[111]	16.9 ± 0.3	10 weeks	5-0-5 agility test	Strength/RSA	1.0
Thomas *et al.*[75]	17.3 ± 0.4	6 weeks	5-0-5 agility test	CMJ DJ	11.4 7.0
Young and Rogers[116]	17.3 ± 0.5 17.5 ± 0.8	7 weeks	Planned AFL test Video-based RAT Planned AFL test Video-based RAT	CODS SSG	0.1 0 0.8 3.8

The dashed lines separate the table into age groups that approximate to pre- (top), circa- (middle) and post- (bottom) peak height velocity; a positive % change represents an improvement in change-of-direction-speed performance.

RSA = repeated sprint ability; SSG = small-sided games; CODS = change-of-direction-speed; CMJ = countermovement jump; DJ = drop jump; AFL = Australian Football League; RAT = reactive agility test.

growth, maturation, and training interact to develop these qualities remains unclear. Of the minimal evidence available, one study has attempted to determine the effects of a short-term (3-week) reactive agility training programme on the perceptual and decision-making components of agility in youth rugby players; however, this programme comprised players aged between 18–20 years old.[118] Participants were allocated to either a control group that continued with regular training, or an experimental group that participated in reactive agility training exercises. These exercises required players to perform movements in reaction to video footage projected onto a large screen. Measures of performance on a reactive agility test and a change-of-direction-speed test were collected before and after the intervention period. While the control group showed no performance changes, the experimental group significantly improved reactive agility performance. Interestingly, while significant changes were reported in reactive agility performance, change-of-direction-speed performance remained unaffected by the intervention. This would suggest that improvements in reactive agility were a result of perceptual and decision-making skills rather than change-of-direction-speed variables. While these novel findings provide some evidence for the trainability of perceptual and decision-making skills, the research was recognized as a preliminary study; therefore, these results should be interpreted with caution. Additionally, while the study used participants from a national youth rugby league competition, the ages of the participants involved means that any understanding of how children and adolescents would respond to similar training interventions during different stages of maturation remains unclear.

Interestingly, while research suggests that repeated exposure to a given stimulus will enhance faster response times, for the health and well-being of youth, and especially young athletes, it should be noted that development of the key perceptual and decision-making determinants identified by Sheppard and Young[16] can be developed with varied practice. Specifically, generic pattern recognition, hand-eye coordination, and decision-making skills can be enhanced when youth are exposed to a variety of activities,[119] additional research shows that a cumulative exposure to a breadth of sporting experiences may promote selective transfer of pattern recall, and ultimately facilitate expert performance.[120] Such an approach would reduce the need for a specialized and narrow approach to the development of sporting talent, which is indicative of the experiences of those children who concentrate on a single sport from a young age. The notion of sport specialization has recently been highlighted as a major concern for young athletes, given the associated risks of overuse injury, overtraining, and eventual dropout from the sport.[121]

Conclusions

Speed and agility are recognized as unique and fundamental movement skills that form the basis of many physical activities, contribute to sports performance, and may be important markers of health in children and adolescents. Unfortunately, our understanding of agility in youth is primarily limited to the physical development of change-of-direction-speed, with limited information available on the perceptual factors that contribute to agile movements in real-world situations. It is clear that speed and change-of-direction-speed develop naturally with growth and maturation in both boys and girls. Similarly, both speed and change-of-direction-speed appear to be sensitive to training in children and adolescents, with a variety of different training methods all shown to promote positive gains in performance. However, there are still considerable gaps in our knowledge; much less information is available regarding the interaction of maturity and training in girls when compared to boys and there is a general lack of well-controlled long-term intervention studies.

Summary

- Speed and agility are fundamental movement skills that contribute to natural play activities, determine success in youth sports, and may be related to health-related fitness. However, speed and agility are independent qualities and should be considered separately.
- A maturational influence on the development of speed is evidenced by the differential timing of periods of rapid development when comparing boys and girls, as well as from longitudinal data which align speed with growth rates. However, it is not entirely clear whether peak gains in speed coincide with peak height velocity or the start of the growth spurt.
- With maturation, sprint mechanics alter, ground contact times increase, and stride frequency is reduced. These changes are more than compensated for by increases in stride length, which drive gains in sprint speed.
- There is minimal literature available on the development and trainability of agility in paediatric populations. The available research has focused on the physical component of change-of-direction-speed, with limited attention given to the perceptual component of agility.
- While speed and change-of-direction-speed are independent qualities they demonstrate similar, non-linear developmental progress; boys and girls perform similarly at a young age, but sex differences become more apparent with the onset of puberty.
- Natural improvements in both speed and change-of-direction-speed are related to growth-related changes in size, as well as qualitative changes in neural-muscle-tendon structure and function.
- Available evidence suggests that gains in both speed and change-of-direction-speed can be achieved using a variety of different short-term training interventions in both children and adolescents, although more research is needed with girls.
- Limited evidence suggests youth involved in sports programmes involving long-term systematic training will improve their speed and change-of-direction-speed more than those not involved in such programmes.
- The type of training and the underpinning adaptations that promote the greatest gains in speed may differ between children and adolescents. Combining strength and plyometric training appears to be an effective method for improving speed in both children and adolescents.
- From the limited evidence available, natural development and training-induced gains in change-of-direction-speed appear to be associated with gains in relative strength.

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