Introduction

Ever since Sid Robinson conducted the first experiment examining the response of children to exercise (Robinson, 1938), the field of paediatric exercise science has continued to advance our understanding of the way in which children respond to training. Now, nearly 80 years since Robinson’s seminal work, the current evidence base shows that children differ to adults in terms of their acute cardiorespiratory response to exercise (Armstrong et al., 2015), metabolic and hormonal responses during exercise (Boisseau and Delamarche, 2000), ability to voluntarily activate muscle (Dotan et al., 2012), and the way in which they recover from high-intensity exercise (Falk and Dotan, 2006). Due to these physiological differences, adult-based training programmes should not be superimposed on young athletes, but rather training prescription should be commensurate with a child’s levels of technical competency, training age, psychosocial maturity and stage of maturation.

The influence of growth and maturation

While notable differences in anatomy and physiology exist between children and adults, there are also clear differentiations between children and adolescents, which are mediated by growth and maturation. For example, force-producing capacities are lower in children when compared to adolescents or adults, partly as a result of the structure (O’Brien et al., 2010), size (Dotan et al., 2012), activation patterns (Dotan et al., 2013), and function (Waugh et al., 2013) of a child’s muscle. Due to these inherent differences, children will typically be less effective at producing and attenuating forces, which may make them more susceptible to reductions in absolute physical performance. From a metabolic standpoint, research shows that children’s metabolic profile favours oxidative metabolism (Ratel et al., 2006a), while recovery rates in youth (especially from high intensity exercise) are shorter than adults (Ratel et al., 2006b, Tibana et al., 2012). The greater fatigue resistance seen in children is typically due to a range of factors during exercise (e.g. smaller muscle mass, higher content of type I fibres, greater muscle oxidative activity, increased fat oxidation and lower impairment in neuromuscular activation and force output) and during recovery (e.g. faster PCr resynthesis, faster clearance of accumulated H+, faster regulation of
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acid-base balance, and faster return of cardiorespiratory parameters to baseline levels) (Ratel et al., 2006a). These two examples demonstrate potential age- or maturity-related effects on differential physiology between youth and adults, and underlines how such differences will likely impact upon training prescription. It should also be noted that as per adults, young athletes require the correct balance between training dosage in order to prepare them for the demands of sport, but also sufficient time for rest and recovery. However, what is unique to child and adolescent populations is that they will also require time outside of training to allow for natural growth processes to occur.

Throughout childhood and adolescence, all systems within the body (e.g. nervous, muscular, skeletal, endocrine) will develop independently and in a non-linear manner. Biological maturation is the process of progressing toward a mature state, and varies in magnitude (extent of change), timing (onset of change) and tempo (rate of change) between different systems in the body (Bennett and Malina, 2008) and between individuals (Lloyd et al., 2014c). Dependent on these variables, youth can be classified as biologically “ahead of” (early maturer), “on time” with (average maturer), or “behind” (late maturer) their chronological age (Malina et al., 2004). This inter-individual difference in biological maturation is evident when comparing a squad of young athletes of the same chronological age who may differ markedly in terms of maturation (Malina et al., 2012, Malina et al., 2015). Research shows that both physical and psychosocial development of children can be influenced by an individual’s level of maturity (Lloyd et al., 2016a). For example, boys who experience maturation at an earlier stage than their peers will invariably be taller and heavier from late childhood and undergo a more intense adolescent growth spurt leading to large gains in muscle size and lean mass, and greater gains in force producing capacity. However, any discrepancies in stature between early, average and late matures are almost nullified by the time they reach adulthood. Research has also shown that early maturing boys report more positive perceptions of their physical self (i.e. strength and power, physical fitness, physical appearance and sport competence) and possess higher levels of self-esteem compared to their peers (Cumming et al., 2012). Due to these preferential factors, it is unsurprising to observe earlier maturing youth choosing, and being selected for, those sports where greater size, strength and power are desirable attributes, such as in tennis (Myburgh et al., 2016), soccer (Malina et al., 2000), or basketball (Torres-Unda et al., 2013).

While certain aspects of growth and maturation are of benefit to performance and sporting success, rapid changes in the magnitude and rate of growth associated with the adolescent growth spurt have been shown to disrupt motor coordination (Philippaerts et al., 2006) and increase the relative risk of overuse and growth-related injury (Kemper et al., 2015, van der Sluis et al., 2014). During the growth spurt, youth are forced to move with increased mass and height of the centre of mass, without concomitant increases in neuromuscular adaptations, which lag behind in the maturational process. Additionally, from a psychosocial perspective, the way in which children are affected from maturing ahead of, or behind, their peers of the same chronological age remain unclear. Cumulatively, existing scientific evidence points to fact that the physical, physiological and psychosocial differences associated with childhood and adolescence makes the art of designing training programmes for youth an interesting and challenging process.

Developing movement skill competency

Determinants of movement skills

Fundamental movement skills (FMS) encompass locomotion, stabilisation and manipulation skills, which serve as building blocks for more complex movements commonly witnessed in sporting situations (Gallahue et al., 2012). Evidence suggests that developing a high level of movement
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Skill competency in youth increases the likelihood of long-term participation in physical activity (Lloyd et al., 2014a). As a result, physically literate children may experience various health-and fitness-related benefits (Lubans et al., 2010), engage in higher amounts of physical activity (Barnett et al., 2009) and potentially reduce injury risk (Larsen et al., 2016) in comparison to their physically illiterate counterparts (Faigenbaum et al., 2016, Hardy et al., 2012). The development of FMS during childhood and adolescence occurs as a result of the interaction between individual, task and environmental constraints (Gallahue et al., 2012), and it is ultimately this interaction of constraints which leads to within- and between-individual variations in rates and magnitudes of motor skill development. Details of the different types of constraints and examples of how they can be manipulated by the strength and conditioning coach are presented in Table 3.1.

Movement competency is a multidimensional concept (Rudd et al., 2016) combining cognitive processing abilities with coordination and adequate amounts of relative strength (Lloyd et al., 2015). Although correct execution of fundamental motor skills requires coordinated sequencing of multimuscle, multijoint, multiplanar movements, there will always be a requirement for complementary force production and force attenuation. Neuromuscular coordination and force production are governed by neural activation and control, and thus it is optimal to target the development of motor skills and muscular strength at a time when the corticospinal tissue in children is highly “plastic” (Myer et al., 2013). Furthermore, the primacy of strength in the acquisition of all other fitness components (Behringer et al., 2011) warrants its inclusion as a training priority during all stages of any young athlete’s development (Lloyd and Oliver, 2012, Lloyd et al., 2016a). Practitioners should not view coordination and muscular strength as separate entities but rather synergistic components of motor skill performance (Cattuzzo et al., 2014) that should be developed concurrently during early childhood.

### Trainability of movement skills

Owing to the movement patterns and biomechanical similarities of FMS with sports-specific skills and daily living tasks (Tompsett et al., 2014), the trainability of movement competency in youth can be viewed as an essential component of training for lifelong physical development. Childhood appears to be the optimal time to develop motor skill competency, as neuromuscular maturation is heightened, due to greater levels of neural plasticity (Casey et al., 2005). However, irrespective of the accelerated maturation of the central nervous system, children will not naturally develop FMS without the opportunity to regularly practice these skills (Hardy et al., 2012). Research has demonstrated that with appropriately designed training programmes, inclusive of

| Table 3.1 Examples of different constraints on motor skill performance and development |
|-----------------------------------------------|--|--------------------------------------------------|
| Constraint | Variable | Example in practice |
| Individual | Height, weight | Tall versus short adolescent male performing a bodyweight squat |
| Structural | Motivation, fear | Confident versus apprehensive child performing a jump from box |
| Functional | Rules | Hopping on one leg versus hopping on either leg in relay races |
| Task | Degree of challenge | Throwing a ball for distance versus throwing at a target |
| Environmental | Flooring | Using a youth training barbell versus a full-size Olympic barbell |
| | Lighting | Horizontal jump on a concrete floor versus gymnastics matting |
| | | Practice in daytime versus floodlit evening training |
Motor skill and strength development stimuli, children and adolescents can make worthwhile adaptations in motor skills (Faigenbaum et al., 2011). Previous meta-analytical data has shown that pre- and early-pubertal youth can achieve approximately 50% greater training-induced gains in motor skills following resistance training interventions compared to adolescents (Behringer et al., 2011). This suggests that motor skills are most trainable during early childhood, advocating the pre-pubertal years as the optimal time to begin fundamental motor skill training.

Prior to the onset of puberty, the training focus should centre around fundamental movement skills, followed by sports-specific skills during later developmental stages (Lloyd and Oliver, 2012). In addition to the development of FMS, strength and conditioning coaches should also look to develop a breadth of athletic motor skill competencies (AMSC), which incorporate upper body pushing/pulling and lower body bilateral/unilateral lower body movements, plyometric abilities, and trunk conditioning activities (Lloyd and Oliver, 2014). Figure 3.1 provides an overview of the AMSC. The use of educational gymnastics to teach movement concepts may offer a different and enjoyable addition to young athletes’ programmes (Baumgarten and Pagnano-Richardson, 2010). Simple bodyweight management tasks involving gymnastic shapes, positions and partner balances can serve as a viable means of promoting multiple fitness components. This holistic approach to the physical training of youth aims to facilitate performance and increase young athletes’ preparedness for the future demands of competitive sport.

Figure 3.1  Athletic motor skill competencies (adapted from Lloyd and Oliver, 2014)
The development of broad ranging FMS is also of particular concern for those involved in early specialisation sports (Myer et al., 2015). Research has shown that these young athletes are potentially at a greater risk of injury due to muscular imbalances resulting from highly repetitive sports-specific training (Myer et al., 2015). Practitioners should attempt to address movement skill deficiencies and/or muscle strength imbalances in these athletes through the development of gross athleticism that has relevance to sports performance, instead of simply attempting to load movement patterns that closely mirror those seen in the sport. Another challenging scenario for strength and conditioning coaches is determining when adolescent athletes who have not previously participated in formalised strength and conditioning should enter their programme. In such a scenario, professionals working with paediatric populations should initially attempt to develop a breadth and depth of FMS and AMSC before progressing them to more advanced modes of training.

Developing strength and power

Determinants of strength and power

Muscle strength and power increase as children transition towards adulthood, often coinciding with changes in body weight and lean body mass (Malina et al., 2004). Considering that muscle cross-sectional area is a major predictor of force production in children (Tonson et al., 2008), a factor that results in the improved capacity to produce force during maturation may be an increase in muscle size (O’Brien et al., 2010). However, when normalised to muscle cross-sectional area (mCSA), adults still produce greater force than children (Falk et al., 2009). Therefore, it can be assumed that additional factors will influence force production as a result of growth and maturation. From a structural perspective, fascicle length increases from childhood through to adolescence (Kubo et al., 2014), which improves force production at higher shortening speeds and over larger length ranges, due to a greater number of sarcomeres in-series (Blazevich, 2006). Similarly, muscle fibre pennation angle increases throughout maturation (Binzoni et al., 2001), which results in a greater physiological mCSA and an increased number of muscle fascicles attaching to the aponeurosis or tendon, both of which increase force producing capacity.

Force production in children and adolescents is also influenced by maturation of the central nervous system, with specific adaptations including improvements in motor unit recruitment (Granacher et al., 2011), firing frequency and neural myelination (Kraemer et al., 1989, Ramsay et al., 1990). As children transition into adolescence, they will naturally improve their ability to recruit their high-threshold type II motor units, thereby enhancing their ability to produce both the magnitude of force output and rate at which the force is developed (Dotan et al., 2013). Other neural adaptations that manifest throughout childhood and adolescence impacting on strength and power production include increased muscle preactivation (Lloyd et al., 2012), decreased co-contraction (Croce et al., 2004), and reductions in electromechanical delay (Waugh et al., 2013). Combined, these structural and neural variables will influence the way in which young athletes can express strength and power during sports, and coaches should be aware of these developmental changes in order to be confident that those adaptations witnessed following a training intervention are not simply reflective of natural development mediated by growth and maturation.

Trainability of strength and power

It is now acknowledged by leading authorities that well-supervised resistance training is a safe and effective training mode for children and adolescents (Lloyd et al., 2014b). Significant improvements in the strength and power of youth have been reported following exposure to a variety
of training protocols, including manual resistance, machine weights, plyometric training, medicine balls and elastic bands (Lloyd et al., 2014b). Research also shows that resistance training in children and adolescents can lead to significant improvements in strength beyond that produced by natural development (Lloyd et al., 2014b); however, the response to strength training may be influenced by maturation, with circa- and post-pubertal children displaying almost twice the gains in strength compared to pre-pubertal children (Behringer et al., 2010).

Meta-analytical data including 42 studies has shown that average resistance training prescription for youth is typically prescribed using 2–3 sets, 8–15 repetitions, and loads of 60–80% 1RM, with training periods lasting approximately 10 weeks (Behringer et al., 2010). However, a more recent meta-analysis that examined resistance training specifically in young athletes attempted to examine the optimal dose–response for youth. The research showed that the most effective training prescription for strength gains required longer periods of training (>23 weeks), the use of heavier loads (80–89% of 1 repetition maximum) and greater training volumes (5 sets of 6–8 repetitions) (Lesinski et al., 2016). Cumulatively, it would appear that as a child becomes more experienced and acquires higher levels of athleticism, resistance training prescription would need to change, especially in terms of the volume and intensity of training.

Recent data indicate that children and adolescents may respond differently to specific types of resistance training (Lloyd et al., 2016b, Radnor et al., 2017). Lloyd et al. (2016) showed that in response to a short-term training intervention, plyometric training elicited the greatest gains in markers of sprint and jump performance in children who were pre-peak height velocity, whereas combined strength and plyometric training was the most effective in eliciting change in the same variables for boys who were post-peak height velocity. On an individual response basis, Radnor et al. (2017) showed that irrespective of maturation, combined strength and plyometric training may serve as the most potent training stimulus for individuals to make short-term improvements in jump and sprint performance (Radnor et al., 2017). Considering that pre-pubertal children experience a natural increase in neural coordination and central nervous system maturation during childhood, the high neural demand during plyometric training may provide an augmented training response, recently termed “synergistic adaptation” (Lloyd et al., 2016b). Similarly, as post-pubertal children experience increases in testosterone and natural morphological changes that facilitate force generation, the combination of plyometric and strength training may result in a heightened maturity-related training stimulus (Lloyd et al., 2016b).

While most children will make positive adaptations from resistance training, there will be large individual variability in the response to resistance training due to the timing and tempo of maturation. Thus, practitioners should routinely change the primary training mode to facilitate long-term adaptation, and prescribe periodised and developmentally appropriate training programmes.

**Developing speed**

**Determinants of speed**

Sprint speed is suggested to develop in a non-linear fashion throughout childhood and adolescence (Malina et al., 2004), with spurts identified during both pre-adolescence and adolescence (Meyers et al., 2015a, Viru et al., 1999). Longitudinal data from boys suggest that peak improvements in sprint speed occur around the period of peak height velocity (Philippaerts et al., 2006). Furthermore, data collected over a two-year period suggest that 13–15 year old
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boys (circa-pubertal) elicit up to twice the improvement in sprint speed compared to 15–17 year olds (post-pubertal) (Hirose and Seki, 2015). Such observations further reinforce the non-linear nature of speed development in youth and the potential influence of maturational processes.

Speed is the product of step length and step frequency (Hunter et al., 2004), and in youth it has been suggested that step frequency is largely stable, with increases in sprint speed proportional to increases in step length and leg length (Schepens et al., 1998). However, more recent research has shown that step frequency may decrease during the pre-pubertal period, offsetting the increases in step length observed during this period, resulting in no increases in sprint performance (Meyers et al., 2015a). Once step frequency stabilised around peak height velocity, increases in speed became apparent (Meyers et al., 2015a). Multiple regression analysis has also indicated that maximal sprint performance in pre-pubertal boys may be more step frequency reliant (58% explained variance) whilst post-pubertal boys are marginally more reliant on step length (54% explained variance) (Meyers et al., 2015b), further highlighting the influence of maturation upon sprint performance in youth.

The role of strength and power as determinants of sprint performance in youth has been consistently supported in the literature (Lloyd et al., 2016b, Meylan et al., 2014a, Rumpf et al., 2012, Rumpf et al., 2015b). Rumpf et al. (2015b) reported that combined horizontal force and power accounted for 98–99% of the explained variance in sprint performance of boys classified as pre- and post-peak height velocity. Recent longitudinal data has also indicated that measures of relative force production alongside relative lower limb stiffness are also important determinants of maximal sprint performance for boys who are pre-pubertal and those experiencing peak height velocity, collectively accounting for 78–98% of the explained variance (Meyers et al., 2016).

Trainability of speed

The literature relating to the most effective training methods to enhance sprint performance in youth is sparse; however, a systematic review on youth sprint training (Rumpf et al., 2012) and a recent resistance training study (Lloyd et al., 2016b) have highlighted that plyometric training may be the most effective method to enhance sprint performance in pre-pubertal male youth, whilst a combined approach may be most beneficial for those post peak height velocity. Furthermore, a recent training study utilising sled-towing reported no significant changes in sprint performance for pre-pubertal male youth, yet significant increases for a combined circa/post-pubertal group in sprint speed, step length and step frequency as well as horizontal force, power and lower limb stiffness elicited during the sprint (Rumpf et al., 2015a). Such observations may question the role of resisted methods of training for sprint performance in youth; however, it is important to note that improvements in sprint performance in pre-pubertal samples have been reported following resistance training (~2.1%), despite the magnitude of these changes being reduced compared to circa (~3.6%) and post-pubertal (~3.1%) groups (Meylan et al., 2014b). It is also important to note that there is a dearth of data pertaining to the effect of free sprinting upon sprint performance in youth, despite this mode of training having the highest potential for transfer to increased sprint performance over a range of distances in adults (Rumpf et al., 2016). These data reinforce that practitioners seeking to develop speed in children and adolescents should provide a varied training programme encompassing a variety of training stimuli, whilst being mindful of the favourable synergistic changes that may occur as a result of mapping the training stimuli with naturally occurring adaptations (Faigenbaum et al., 2016, Lloyd et al., 2016b).
Developing endurance

Determinants of endurance

Endurance is synonymous with the aerobic system and the ability to maintain lower intensity exercise over a long duration. However, the aerobic system also enables recovery to take place following bouts of high-intensity exercise. Endurance is determined by three physiological factors: peak oxygen uptake ($V_\text{O}_2\text{peak}$), the anaerobic threshold and economy. Peak oxygen uptake is the primary determinant of endurance exercise and is the product of cardiac output and the ability of the muscle to extract and utilise oxygen. Absolute values of $V_\text{O}_2\text{peak}$ increase by 150% in boys and 80% in girls between the ages of 8 and 16 years old (Armstrong and Welsman, 1994). These large gains are driven by growth in body size, heart size and blood volume increasing cardiac output. When compared to girls, boys experience greater gains in size during adolescence and also benefit from greater increases in red blood cells and haemoglobin, further enhancing oxygen transport capacity (Malina et al., 2004). Conversely, girls also have to contend with increased fat mass during adolescence and this will negatively affect events where body mass has to be moved.

In terms of muscle metabolism immature children have lower levels of glycolytic activity and are more reliant on aerobic energy compared to more mature children and adults. This means immature children produce less lactic acid, suffer less fatigue during exercise, can recover more quickly and can maintain exercise at a higher relative physiological intensity. Previous research has reported that the anaerobic threshold occurred at 71% of $V_\text{O}_2\text{peak}$ in 5–6 year old boys, reducing to 61% of $V_\text{O}_2\text{peak}$ in 15–16 year adolescent boys and with a similar trend observed in girls (Reybrouck et al., 1985). Running economy improves steadily with age in children and adolescents, with the oxygen cost of running at a set speed reducing by almost 20% from 5 to 18 years old in boys and girls (Mahon, 2008). Changes in body size, increases in strength, improvements in technique and reduced co-contraction may all help explain improvements in economy (Bar-Or and Rowland, 2004). The accumulation of the above physiological changes means that endurance performance improves markedly due to maturation, with one mile run times decreasing by ~20% in boys and ~6% in girls between the ages of 9 and 17 years old (Catley and Tomkinson, 2013).

Trainability of endurance

The “trigger hypothesis” suggested that children will not be responsive to training prior to the onset of puberty and the accompanying increases in circulating androgenic hormones (Katch, 1983). However, a series of review articles and expert statements examining a large body of evidence have all concluded that children and adolescents are responsive to aerobic training throughout maturation (Armstrong and Barker, 2011, Baxter-Jones and Maffulli, 2003, Baquet et al., 2003, Harrison et al., 2015, McNarry et al., 2014). Most of the evidence has focused on the trainability of $V_\text{O}_2\text{peak}$, with research suggesting that short-term training interventions typically improve $V_\text{O}_2\text{peak}$ by ~5–8% in both boys and girls (Armstrong and Barker, 2011, Baquet et al., 2003).

Table 3.2 provides guidelines to consider when designing an aerobic training program for youth. The most important factor is to ensure the intensity of exercise is sufficiently high. In team sports, small-sided games can provide a fun and stimulating challenge while providing a high exercise intensity that will stimulate improvements in endurance (Harrison et al., 2015), with less technically demanding games allowing children to maintain a higher work intensity (Harrison et al., 2014). Interval training has also been shown to be successful at increasing the anaerobic threshold of youth (Mahon and Vaccaro, 1989, McManus et al., 2005). It has been
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stated that improvements are dependent on exercise being completed at a high intensity (Armstrong and Barker, 2011) and it is likely that the anaerobic threshold is more sensitive to training than \( \dot{V}O_2^{peak} \) in children and adolescents (Mahon, 2008). The benefits of endurance training to improve economy in youth are equivocal. It may be that long-term endurance training is needed to improve economy, or that other forms of training (such as strength and plyometric training) are more effective for improving economy, but more research is needed to confirm this.

Programming for athletic development

While practitioners will intuitively adopt their preferred philosophy of periodisation, it is generally accepted that in order to elicit the greatest adaptive response, systematic planning of sequential blocks of training is more effective than random and unplanned training. Recent literature has advocated that the training of young athletes should be viewed as a long-term process, to avoid coaches, parents, or the athletes themselves seeking short-term gains at the expense of the overall health and well-being of the child (Lloyd et al., 2015). While all youth can make worthwhile gains in physical performance in response to structured strength and conditioning programmes, coaches should never increase the intensity, volume or frequency of training at the expense of technical competency or the degree of enjoyment of the child.

Existing periodisation literature for training youth remains relatively short-term in nature. Behringer et al. (2010) published a meta-analysis examining the effectiveness of resistance training in children, and showed that the mean intervention period across the 42 included studies was just 9.9 ± 3.7 weeks. However, while the evidence base of long-term, periodised training interventions in young athletes remains somewhat sparse, more recent research (albeit lacking in specific training details) has shown the beneficial effects in young athletes of 2-year periodised training programmes on measures of strength (Keiner et al., 2013), power (Sander et al., 2013), and change-of-direction-speed (Keiner et al., 2014). Of note, Keiner et al. (2013) showed the potential trainability of strength in young athletes, with trained 16–19 year old soccer players expressing relative strength levels of 2.0×body weight in the squat exercise.

When looking to periodise training programmes, coaches will invariably separate the annual training plan into a combination of different periods, namely the: i) preparation period, ii) competition period and iii) transition period (Haff, 2013). The purpose of the preparation period is to suitably prepare the athlete for the demands of the next block of training (e.g. competition

<table>
<thead>
<tr>
<th>Genetics</th>
<th>Responsiveness to training will be influenced by genetics</th>
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<tbody>
<tr>
<td>Maturity</td>
<td>There is no need to align training to specific periods of maturation</td>
</tr>
<tr>
<td>Baseline fitness</td>
<td>Expect those with lower initial fitness to respond more to training</td>
</tr>
<tr>
<td>Type of exercise</td>
<td>Continuous and interval training can both be successful, but the latter is likely to provide better results</td>
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<tr>
<td>Frequency</td>
<td>Three sessions per week</td>
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<tr>
<td>Session duration</td>
<td>30–60 min</td>
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<tr>
<td>Intensity</td>
<td>Intensity is crucial, 85% HRmax to all-out exercise</td>
</tr>
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Table 3.2 Factors to be considered when designing training programmes to maximise the improvement in the \( \dot{V}O_2^{peak} \) of youth (Armstrong and Barker, 2011; Baquet et al., 2003; Harrison et al., 2015; McNarry et al., 2014)
period) and is traditionally sub-divided into the general preparation phase (GPP) and the specific preparation phase (SPP). Classic periodisation literature suggests that the GPP should focus on using a variety of training means to develop the foundations of the athlete’s training base across a range of fitness components and movement skills (Issurin, 2009). Conversely, the SPP takes on a more sport-specific training emphasis, ultimately trying to capitalise on the adaptations realised within the GPP (Bompa and Haff, 2009). Given the current prevalence of physical inactivity in youth (Tremblay et al., 2014) and that it is not uncommon for young athletes who are entering sporting pathways to show a lack of proficiency in key athletic movement patterns (Parsonage et al., 2014, Woods et al., 2016), coaches should devote more time to the GPP as opposed to advancing young athletes to the SPP before they are physically prepared to tolerate more sport-specific training. Within the GPP, coaches should seek to develop a breadth and depth of athletic motor skill competencies in their young athletes, aiming to develop both the quality of movement and the ability to produce and attenuate force. This approach is much like building a house, whereby the bricks need to be positioned carefully in straight lines (movement quality), but concrete (muscle strength) is required to make the house robust. Figure 3.2 provides an overview of how strength and conditioning coaches can approach the development of force-producing capabilities in young athletes. Specifically, initial focus should be on enhancing the athlete’s ability to produce force with control, following which emphasis can then be placed on increasing the rate of force production as most sports or recreational activities require rapid expressions of force. Finally, the application of force in the required direction and at the appropriate rates relevant for sports can then be targeted to optimise the transfer of training effect. As a caveat, coaches should remember that strength is the foundation for explosive movement (Cormie et al., 2011); thus, practitioners are advised to strategically develop this physical quality with their athletes prior to seeking more sports specific adaptations.

Novice athletes should remain in the GPP for a large proportion of the year (Haff, 2013), even if this includes portions of the competitive period, as they will likely continue to show physical adaptations simply from improving base levels of athleticism. However, for those athletes who have been integrated within a long-term athletic development pathway for a greater period of time, the coach will invariably need to be more systematic and intricate with their programming. For athletes that have accumulated more training experience, it is reasonable to expect more time being devoted to the SPP as they seek to build on their already developed athletic qualities. Recent evidence, albeit with small sample sizes, shows diminishing increases in strength and power as training experience increases, and that worthwhile changes in both qualities may take longer in those athletes who are closer to their ceiling potential (Baker, 2013). Therefore, more sophisticated arrangements of mesocycles (typically blocks of 4–6 weeks) and more targeted

![Figure 3.2 Systematic progression of force production](image-url)
Young athletes

microcycle design (typically 7 days) will likely become necessary as the young athlete progresses along their sporting pathway.

Irrespective of training history, a young athlete needs to be afforded transition periods to enable recovery and regeneration from the multiple demands of training, competing and other stressors (e.g. school or social demands). However, unique to youth populations is that these periods of active recovery are necessary to facilitate growth-related processes to occur (Lloyd et al., 2016a). These phases are also important to safeguard against the negative effects of accumulated fatigue and potential risks of overuse injury. An example of this is apparent in recent recommendations whereby young baseball pitchers are encouraged to pitch for no more than 8 months within a 12-month time frame to reduce the risk of overuse injury in the shoulder (Rice et al., 2012). Abiding by the use of transition periods can be a challenging process for young athletes, as many will be involved in multiple sports during their childhood and adolescent years. For these multisport athletes, sporting seasons can trail one another or even overlap (e.g. winter and summer sports), resulting in youth not having a clear break in competition throughout the year. This underlines the need for a holistic and well-rounded approach to developing young athletes, where communication is a priority between those individuals involved in their development, such as parents, sports coaches, strength and conditioning coaches, and medical personnel.

Summary

It is clear that the most effective way to develop young athletes is for coaches to possess excellent levels of pedagogical and coaching skill, in addition to a sound underpinning knowledge of paediatric exercise science. Children and adolescents are unique populations that require developmentally appropriate training prescription to foster the long-term development of athleticism. While Olympic medals and World Championships are not won during the developing years, strength and conditioning coaches have a vital role to play in laying the foundations that will serve young athletes for a lifetime of successful sports participation.

References

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