SSI-NYSI CONSENSUS STATEMENT ON STRENGTH & CONDITIONING FOR YOUTH ATHLETES

Abstract

Strength & Conditioning (S&C) practices have been gaining popularity among youth in recent years[1]. This is partly attributed to the rise in sports participation over the decade and a growing interest among parents and coaches to enhance sports performance in youth[2,3]. However, the rise of sports participation correlates with an increased prevalence of sports-related injuries[3,4]. Therefore, there is a need to provide information on safe and effective S&C practices for coaches working with youth athletes to encourage sports participation, reduce injury risks, and acquire a competitive edge[5,6,7]. To guide these objectives, the National Youth Sports Institute (NYSI) and Singapore Sport Institute (SSI) have put together a joint consensus statement with the latest evidence-based training recommendations to share best practices and inform sports coaches on the benefits and safety of S&C for youth athletes[8].

Introduction

Recently, the National Youth Council (NYC) reported an increase in sports participation of 10% from 2011 to 2018 among youths aged 15 to 19 years old[9]. The NYSI was launched in 2015 to "value-add and positively impact the Singapore youth sports ecosystem" with SSI. Both organisations work collectively to drive the development of youth sport through the following functional areas: (i) Talent identification & development; (ii) Youth coaching; (iii) Athlete life management; and (iv) Sports science. Under the area of sports science, both S&C departments support the sporting development of

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[9] NYC Annual Youth Report 2019

the nation's best sporting talents across a physical preparation spectrum that involves movement skills proficiency, physical capability, and metabolic capacity for athletic success.

Similar to sports training, S&C programmes take into consideration the movement maturation and loading progression compatible with the technical ability of the youth athlete[1,10]. An array of benefits accompanies a well-planned and supervised S&C session for youths[4,5,11]. These sessions can trigger positive neuromuscular adaptations to enhance muscular strength, motor skills, and competitive fitness while reducing the risk of injury[4,11,12]. Other important considerations when devising an S&C programme during the period of growth and maturation are the athlete's chronological, biological, and training age[2,13,14]. These factors will guide the coach in determining the appropriate exercise variation, volume, intensity, and other training-related factors. Thus, reducing the risky effects of over-training or over-reaching[5].

This consensus statement will explain the various constituents of S&C involving strength development, speed development, agility training, plyometric training, and metabolic conditioning throughout the stages of growth and maturation. The paper will also further elaborate on and recommend training progression guidelines for youth athletes.

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Definition

- Strength & Conditioning (S&C) – Sport physical preparation training that includes strength development, speed development, plyometric training, agility training, and aerobic fitness
- Children – Girls and boys who have not yet developed secondary sexual characteristics (approximately up to the age of 11 years old & 13 years old respectively)[5,6]
- Adolescence – Period of life between childhood and adulthood (girls between 12 – 18 years old and boys between 14 – 18 years old are generally considered as adolescents)[5,6]
- Youth – A global term which includes both children and adolescents[5]
- Pre-Pubescent – Period before the onset of puberty
- Circa-Pubescent – Adolescence period starting from the onset of puberty
- Post-pubescent – Period after the completion of puberty
- Growth – Measurable changes in size, physique, and body composition[15]
- Maturation – Variable timing and tempo of progressive change within the human body[15]

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Resistance Training

Significance of Resistance Training on Strength Development

The ability to generate high neuromuscular force and power is important for many sports[16]. A well-planned resistance training programme prepares the athlete for the demands of the sport and reduces injury risks through an understanding of sport-specific movements and its corresponding injury profile[4,5]. It may also expedite an adolescent athlete's neuromuscular growth spurt[17]. Regular resistance training has been found to have a positive effect on the intermediaries of physical fitness such as muscle strength, muscle power, linear sprint, agility, and sports specific performances[18]. It has also been shown to improve physical and psychological health markers that include cardiovascular fitness, well-being, mood, and self-appraisal[13,19].

Effects of Growth and Maturation on Strength Development

Pre-pubescent strength gains are likely mediated by neurological factors[20,21]. These inherent strength gains are probably due to the maturation of the central nervous system (CNS) and motor neuron refinement (e.g. enhanced motor unit recruitment, firing, synchrony, and neural myelination)[22]. Prior to puberty, blood concentrations of anabolic hormones are low hence, limiting the potential for significant changes in muscle architecture[20,21]. Upon the onset of puberty, youths experience exponential growth and an increase in muscular strength, and size. A distinction in inherent strength gains between genders can also be observed[23,24]. While male athletes tend to exhibit accelerated gains in strength, female

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athletes display a steadier and predictable increment[15,25]. These differences can be attributed to the maturation of the CNS and the concentration of sex androgen[10,23]. Nevertheless, both male and female athletes benefit from resistance training and studies have shown no difference in trainable improvements in muscle strength[18].

The period of adolescence is also an ideal time for the development of bone mass and structure. Youth athletes are encouraged to participate in regular resistance training during this period to optimise these musculoskeletal health benefits[5]. While there may be no clear evidence indicating an adverse effect on linear growth or height due to resistance training[26], S&C practitioners and coaches should learn to identify the period of peak height velocity (PHV) for the youth athlete through quarterly height monitoring[20]. During this period of growth, the development of skeletal structures may precede muscle growth, causing structural imbalances, complications in motor coordination and may increase the incidence of growth-related pains and injuries. Resistance training during this specific period should be well-supervised and diversified to reduce the abnormality of movements[27].

Recommended Guidelines for Resistance Training (Table 1)

Numerous studies have undeniably concurred that resistance training performed with proper supervision is safe for youths[6,18,28]. The resistance training programme should be age-appropriate and follow a sensible progression pathway. Programme design should take into consideration an athlete's stage of maturation, training age, fundamental movement skills (FMS) competency, technical lift proficiency, existing strength levels, and psychosocial factors[5,6]. Technical lift competency through a range of basic exercises should be prioritised before external load progressions are considered. Bodyweight exercises introduced in the initial phases can be an excellent start point. Once proficiency has been established, the difficulty of the bodyweight exercises can be progressed by alternating any of these variables:

- Movement plane
- Gravity
- Movement range
- Time under tension (TUT)/Contraction speed

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- Limb leverage
- Stability
- Type of contraction

Exercise variations should be individualised depending on the athlete's proficiency in the exercise movement. Other modalities such as free weights, resistance bands, medicine balls, and manual resistance may also be utilised as variations or progressions to an exercise[6]. Once an athlete has achieved movement proficiency, free weights should be prioritised to constantly provide additional stimulus[29]. Exercise progressions should also seek to challenge the movement quality, coordination and rate of force development (RFD) of the youth athlete. The number of repetitions prescribed should be exercise dependent and objectively driven to suit the training requirements. One to three repetitions of an exercise may be performed when teaching technique to allow for real-time feedback.

Youth athletes do not have to train to muscular failure during resistance training as similar gains in strength and hypertrophy can still be elicited by other means[30,31]. Besides, this methodology tends to slow down post-session recovery and thus, hinder performances during sports training if the youth athlete is not allowed sufficient recovery, increasing the risk of injury[31]. Special consideration to loading should also be given during the period of PHV where the athlete may experience growth-related pains and injuries[27]. As cases present, coaches can consider using alternative loading to allow for continuation and maximisation of sessions without exposing the youth athlete to increased injury risk[32].

To track strength progressions, predictive equations to estimate 1RM values from submaximal loads (3-5RM strength test protocols) may be utilised[33]. However, strength tests should always be carried out under qualified supervision, and only prescribed after technical competency with external loading has been established.

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Table 1. Recommended guidelines for resistance training progression[5,11,34,35,36,37,38,39].

Level of Development	Beginner	Intermediate	Experienced	Advanced
Repetitions	8 – 15	6 – 10	5 – 8	2 – 5
Sets	1 – 2	2 – 4	2 – 4	2 – 5
Exercise Per Session	6 – 10	3 – 6	3 – 6	2 – 5
Exercise Selection	Modified bodyweight exercise with light resistance	Introduction to simple free weights exercises where appropriate	Progression of free weights exercise with the introduction of complex lifts	Introduction of complex multi-joint movement and programme routines
Intensity (%1RM)	Bodyweight, 50 – 70%	60 - 80%	70 - 85%	85 - 100%
Repetition Velocity	Moderate – Fast	Moderate – Fast	Fast – Maximal	Maximal
Rest Intervals	1 min	1 – 2 min	2 – 3 min	2 – 5 min
Training Frequency	2 – 3	2 – 3	2 – 4	2 – 5
Recovery (between sessions)	72 – 48 h	72 – 48 h	48 h	48 – 36 h

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Speed Development

Significance of Speed Development for Youths

Speed is a distinguishing factor of success across youth and senior competitions[40,41]. In the context of this consensus statement, speed refers to the ability to move rapidly from one point to another. The definition of speed can include various sub-components; In particular, acceleration, max velocity, and game speed[42,43,44]. Failure to nurture this movement as the youth athlete develops may hinder the progression of complex sports skills in the future[45].

Effects of Growth and Maturation on Speed Development

Speed development appears to be unpredictable throughout the pre-pubescent and circa-pubescent period. It is well documented that genetic determinants such as an athlete's stature, body mass, maturity status, and age contribute to sprint performance in youth athletes[43,44,46]. Regardless, accelerated speed improvements during these phases can be attributed to neuromuscular (motor recruitment and coordination) and endocrine-mediated (anthropometry and structural changes, development of anaerobic metabolism) changes during pre- and circa-pubescent periods[47].

Throughout pre-pubescence, both genders will experience the greatest improvements in sprint performance[43,48]. Similar to strength development, the rapid development of speed pre-PHV is attributed to the maturation of the CNS through increased myelination of nerve cell axons and enhanced inter-

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and intra-muscular coordination[6,49]. However, upon the onset of PHV, male athletes continue to experience continued improvements in speed development compared to their female counterparts circa- and post-PHV[50,51,52]. This may be explained by the decrease in relative peak force of the lower limb in female athletes during pubescence due to an increase in fat mass during peak weight velocity (PWV) that occurs in the months post-PHV[48]. However, practitioners should note that while most of the circa-pubescent males would experience improvements in speed, high volumes of sprint training for this group may not be optimal, and may lead to injury. This is especially applicable if rapid growth in limb length does not match the pre-requisite strength required to control the body in motion[44].

Recommended Guidelines for Speed Development (Table 2)

Trainable attributes such as the relative joint stiffness and the relative maximal force applied by the lower body have a positive influence on sprint speed regardless of gender or stage of maturity[6,53]. An athlete's ability to generate a high amount of force during ground contact is especially important to improve sprint performance[54,55]. This ability is influenced by positive changes in the relative force applied, and concurrent increment in muscle mass and structural growth thus, improving stride length and sprint speed[44,56].

FMS, coordination, stabilisation, and proprioception training contribute to speed development in youths[45]. Locomotor skill development as part of FMS should progressively include teaching proper running gait and mechanics of sprinting from childhood with simple chasing games such as tag. Coordination patterns should constantly be reinforced during the pubescent period to counter the effects

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of rapid changes in body structure during puberty. Resistance and plyometric training are effective methods to develop speed due to their abilities to influence neural and structural adaptations.

Table 2. Recommended guidelines for speed training progression[43,44,55,57,58,59]

Stages of Development	**Primarily Neural Adaptations**		**Structural and Neural Adaptations**	
	Early Childhood (Neural Adaptation)	**Pre-Pubescent**	**Circa-Pubescent**	**Late Adolescence**
Objective	FMS (locomotor)	Sprint technique and resisted sprints	Sprint technique, resisted sprints and maximal sprints	Maximal sprints
Complimentary Training Selection	Physical literacy, strength training	Plyometric, strength training, coordination, FMS	Plyometric, strength training, coordination, hypertrophy	Plyometric, strength training, coordination, complex training
Repetitions	10 – 20 m	10 – 20 m	40 – 60 m	40 – 60 m
Sets	≤16	≤16	3 - 5	3 - 5
Intensity	Sub-maximal (70 - 90%)	Sub-maximal (70 - 90%)	Maximal 90 - 100%	Maximal (90 - 100%)
Rest Intervals	1.5 – 2 min	1.5 – 2 min	5 – 7 min	5 – 7 min
Training Frequency	-	1 - 2	2 – 3	2 - 3
Recovery (between sessions)	48 – 72 h			

57 Low, D., Harsley, P., Shaw, M., & Peart, D. (2015). The effect of heavy resistance exercise on repeated sprint performance in youth athletes. *Journal of sports sciences*, *33*(10), 1028–1034. https://doi.org/10.1080/02640414.2014.979857

58 Moran, J., Sandercock, G., Rumpf, M. C., & Parry, D. A. (2017). Variation in Responses to Sprint Training in Male Youth Athletes: A Meta-analysis. *International journal of sports medicine*, *38*(1), 1–11. https://doi.org/10.1055/s-0042-111439

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Plyometric Training

Significance of Plyometric Training for Youths

Dynamic sports such as football, rugby, tennis, and athletics regularly impose high impact forces on the body. This reinforces the need to develop the capacity to consistently engage the stretch-shortening cycle (SSC) of muscle contraction for high force production, and absorption in youth athletes[60,61,62]. Multiple studies have shown that resistance training incorporating plyometric can be applied to improve RFD, force production and muscular power, leading to greater running speed, agility, and improved running economy[63,64,65].

Effects of Growth and Maturation on Plyometric Development

The SSC develops with age as it undergoes maturity-related changes and is largely influenced by structural components and neural factors[66]. It has been categorised into fast and slow actions based on the ground contact time threshold of 250 milliseconds[66]. These structural components comprise of muscular size, muscle pennation angle, fascicle length, tendon stiffness, and joint stiffness. Neural factors include motor unit recruitment, neural coordination, pre-activation, and stretch-reflex response[61]. However, the underpinning mechanism behind the SSC development remains unclear[61,62]. It has been suggested that the best way to develop SSC properties is through plyometric training[62]. Improvements to performance markers and lower incidences of sports-related injuries have been reported in studies that include plyometric training[66,67,68].

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Recommended Guidelines for Plyometric Training (Table 3)

As with all other constituents of S&C, plyometric training requires a sensible approach to progression to enhance athletic performance while simultaneously reducing the risk of injury. It is recommended that the plyometric training programme for youth athletes are individualised and carefully considers the stages of growth and maturation[66]. The loading of plyometric training is largely dependent on the selection of exercises and the corresponding stress on the targeted muscle-tendon unit. The plyometric training programme should begin with low-intensity drills focusing on land mechanics and force production capacity. Progression to higher intensity drills can be introduced as the youth athlete demonstrates proficiency in the land and jump mechanics. Coaches may adopt the following principles outlined in Figure 1 to ensure a logical sequence to progress plyometric training depending on the individual's movement maturity, proficiency, and work capacity.

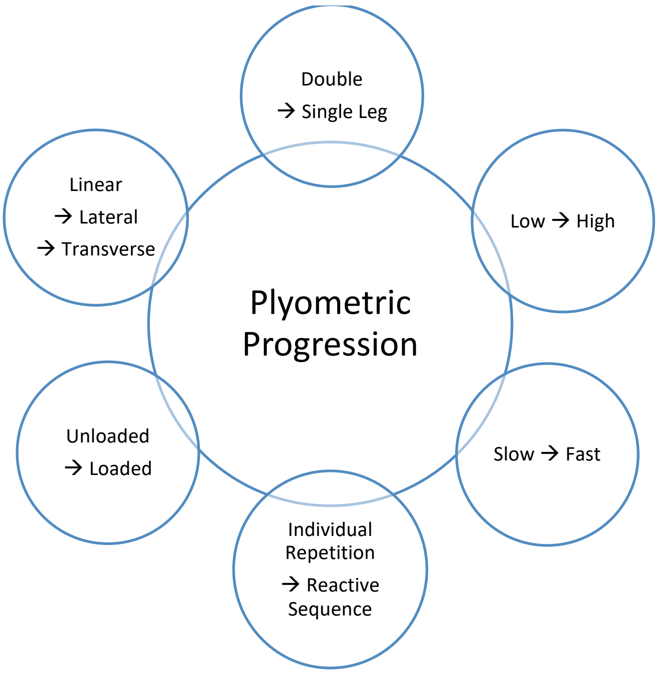

Figure 1. Plyometric progression.

Ground contact time and Reactive Strength Index (RSI) measurements can be utilised as measures for fatigue management when determining plyometric training volumes[69]. It will ensure that the quality of plyometric takes precedence over quantity done under fatigue, minimising injury risk. Eventually, these measurements can also be used as modalities to maximise motivation and performance outcomes as more structure is introduced into plyometric training[69]. Ground contact time will enable the coach to precisely determine the type of SSC (slow or fast) utilised during plyometric training to achieve a desired training objective. RSI refers to an individual's ability to transit quickly

[69] Flanagan, E. P., & Comyns, T. M. (2008). The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength & Conditioning Journal*, *30*(5), 32-38.

from an eccentric to concentric contraction and is a measure of the athlete's reactive vertical jump capacity as depicted by the formula stated below[69,70]:

$$RSI = \frac{Jump\ Height\ (m)}{Ground\ Contact\ Time\ (s)}$$

Apart from monitoring ground contact time and RSI, sufficient rest should be provided between sessions of plyometric training to avoid the occurrence of maladaptive responses from over-training, over-reaching, and overuse injuries in youth athletes[71]. On a micro-scale, recovery between sets of plyometric exercises should consequently be extended as the intensity increases.

[70] Young, W. (1995). Laboratory strength assessment of athletes. *New Stud Athlete*, 10, 88–96,

[71] Scantlebury, S., Till, K., Sawczuk, T., Phibbs, P., & Jones, B. (2020). Navigating the Complex Pathway of Youth Athletic Development: Challenges and Solutions to Managing the Training Load of Youth Team Sport Athletes. *Strength & Conditioning Journal*.

Table 3. Recommended plyometric training progression[62,66,72].

Stages of Development	**Early Childhood (Neural Adaptation)**	**Pre-Pubertal**	**Circa-Pubertal**		**Circa-Pubertal – Late Adolescence**	
Structure	Unstructured	Low	Moderate	Moderate – high	High	High
Objectives	FMS – Locomotion (run, skip & hop)	Jumps from a standing position & jumps in place – low amplitude jump	Bilateral to unilateral hops – low amplitude plyometric	Force production & absorption – higher amplitude jump-land training	High-intensity plyometric – bounding, hurdle jump/hop combo	High-intensity plyometric – depth jump, resisted bounding
Repetitions	NA	6 – 10	6 - 10		190 – 230 Ground contact (16 years old and above)	
Sets	NA	1 – 2	2 – 3 or 185 – 205 Ground contact (13 to 16 years old)			
Intensity	Low	Low	Moderate	Moderate	High	High
Rest Intervals	1 – 3 min	1 – 3 min	2 – 4 min	2 – 4 min	3 – 5 min	3 – 5 min
Training Frequency	2 – 3/ wk (non-consecutive days)					
Recovery (between sessions)	48 – 72 h (non-consecutive days)					

[72] Lubans, D. R., Morgan, P. J., Cliff, D. P., Barnett, L. M., & Okely, A. D. (2010). Fundamental movement skills in children and adolescents: review of associated health benefits. *Sports medicine (Auckland, N.Z.)*, *40*(12), 1019–1035. https://doi.org/10.2165/11536850-000000000-00000

Agility Training

Significance of Agility Performance in Sports

Agility is defined as "a rapid whole-body movement with change of speed or direction in response to a stimulus"[73]. The ability to process and respond to a variety of stimuli and change direction without losing speed nor balance is a strong determinant of success in competitive sport. This is highly evident in sports such as football, netball, badminton, and fencing where athletes are required to constantly react to opponents or targets, demanding superior agility and speed. Agility can be broken down into 2 sub-qualities: (i) Change of direction speed (CODS); and (ii) Reactive agility (RA) training[74].

CODS is a sub-quality in which upcoming actions are known and reactions can be pre-planned[75]. Performance factors of CODS include straight-line running speed, lower limb strength, power, and anthropometry[75]. RA requires the athlete to instantaneously assess visual cues and react immediately and correctly to the situation as presented[74].

Effects of Growth and Maturation on Agility Development

CODS has been suggested to improve naturally throughout childhood and adolescence in a non-linear manner[76,77]. While there is limited research in the paediatric and youth athletic populations, inferences can be made by the sub-components of CODS and cognitive function respectively[10]. During the pre-pubescent years, similar developmental capacities for speed and agility-related tasks are observed in males and females as speed and strength are crucial to CODS[78]. To develop and optimise the coordination and movement patterns required in CODS, pre-pubescence may be the window to rapidly develop this fitness quality due to the rapid improvements in strength and speed; as well as the neurological factors described in the previous sections. Upon the onset of puberty, gender-associated

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[73] Sheppard, J. M., & Young, W. B. (2006). Agility literature review: classifications, training and testing. *Journal of sports sciences*, *24*(9), 919–932. https://doi.org/10.1080/02640410500457109
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[77] Lloyd, R. S., Read, P., Oliver, J. L., Meyers, R. W., Nimphius, S., & Jeffreys, I. (2013). Considerations for the development of agility during childhood and adolescence. *Strength & Conditioning Journal*, *35*(3), 2-11.
[78] Young, W. B., James, R., & Montgomery, I. (2002). Is muscle power related to running speed with changes of direction?. *Journal of sports medicine and physical fitness*, *42*(3), 282-288.

differences with growth can be observed. This is attributed to the dose-response relationship between circulating testosterone levels, muscle mass, and strength that account for the ergogenic advantage observed in young male athletes[79].

Youths should indulge in a variety of sporting activities to benefit from an enhanced decision-making ability. Exposure to multiple sports has been suggested to improve the decision-making process due to the different cognitive stimulation across a wide variety of game situations[80,81]. Continuous development of perception and decision-making skills can promote expert performance while minimising the necessity for early specialisation and the associated injury risks[80]. It should also be noted that higher-level athletes tend to perform better in agility tests compared to lower-level athletes[82,83].

Recommended Guidelines for Agility Training (Table 4)

Coaches should take into consideration determining factors involved in both CODS and RA when planning an agility training programme. The youth athlete should be constantly challenged in their visual perception, spatial awareness, and decision-making components[84,85]. A variety of cross-sport and sport-specific game situations can be considered through structured and unstructured play to encourage the development of the sub-qualities of agility.

Commonly utilised as a training component in team sports, small-sided games (SSGs) are often played in reduced pitch areas with modified rules and lesser players to vary drill intensities and objectives[86]. SSGs have been suggested to be effective in improving leg power, sprints, CODS, and

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[79] Handelsman, D. J., Hirschberg, A. L., & Bermon, S. (2018). Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. *Endocrine reviews*, *39*(5), 803–829. https://doi.org/10.1210/er.2018-00020

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[84] Salmela, V. (2018). Effects of agility, change of direction and combination training on agility in adolescent football players.

[85] Serpell, B. G., Young, W. B., & Ford, M. (2011). Are the perceptual and decision-making components of agility trainable? A preliminary investigation. *Journal of strength and conditioning research*, *25*(5), 1240–1248. https://doi.org/10.1519/JSC.0b013e3181d682e6

[86] Halouani, J., Chtourou, H., Gabbett, T., Chaouachi, A., & Chamari, K. (2014). Small-sided games in team sports training: a brief review. *Journal of strength and conditioning research*, *28*(12), 3594–3618. https://doi.org/10.1519/JSC.0000000000000564

hence agility[87]. However, SSGs might limit individual agility performance potential due to the variability between individual work outputs[88].

Traditional tag games are typically played in large groups using organisation lines, circles, or having random chasing of fleeing targets by taggers[89]. As coaching evolves, it has been suggested for the game of tag to include the teaching of specific skills and strategies to emphasise on movement efficiency and effectiveness[89,90]. Below are four important strategical aspects of the game[89]:

- Balanced and alert;
- CODs in avoiding tags;
- RA to tag targets; and
- Spatial awareness of surroundings.

To successfully increase learning and participation, the game of tag should emphasise on tactical objectives that require attributes such as balance, deception, change of direction speed, spatial awareness, and the ability to dodge obstacles[89,90].

Stages of Agility Development

a. FMS[77]
    - Locomotion, exercise movement skills & jump-land mechanics
b. CODS[91]
    - Static drills and foot placement (Figure 2)
    - Movement Matrix (Figure 3)
    - COD Mechanics Integration (Figure 4)
c. RA
    - SSGs, Tag Games

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[87] Chaouachi, A., Chtara, M., Hammami, R., Chtara, H., Turki, O., & Castagna, C. (2014). Multidirectional sprints and small-sided games training effect on agility and change of direction abilities in youth soccer. *Journal of strength and conditioning research*, *28*(11), 3121–3127. https://doi.org/10.1519/JSC.0000000000000505
[88] Davies, M. J., Young, W., Farrow, D., & Bahnert, A. (2013). Comparison of agility demands of small-sided games in elite Australian football. *International journal of sports physiology and performance*, *8*(2), 139–147. https://doi.org/10.1123/ijspp.8.2.139
[89] Belka, D. E. (1998). Strategies for teaching tag games. *Journal of Physical Education, Recreation & Dance*, *69*(8), 40-43.
[90] Belka, D. E. (2006). What Do Tag Games Teach? *Teaching Elementary Physical Education*, *17*(3), 35-36.
[91] Jeffreys, I., Huggins, S., & Davies, N. (2018). Delivering a gamespeed-focused speed and agility development program in an English Premier League Soccer Academy. *Strength & Conditioning Journal*, *40*(3), 23-32.

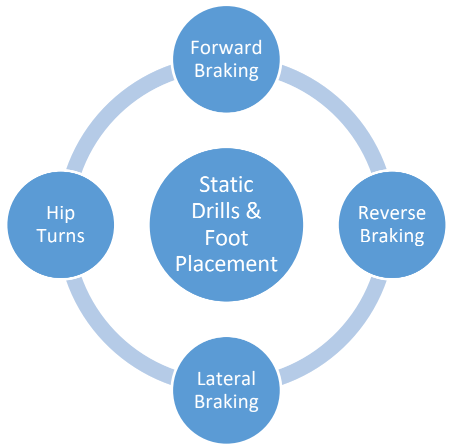

Figure 2. Static drill & foot placement.

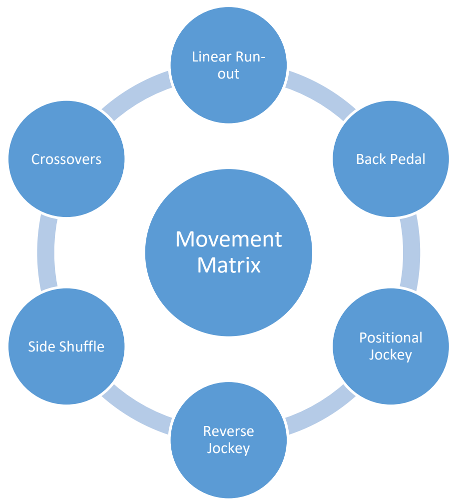

Figure 3. Movement matrix.

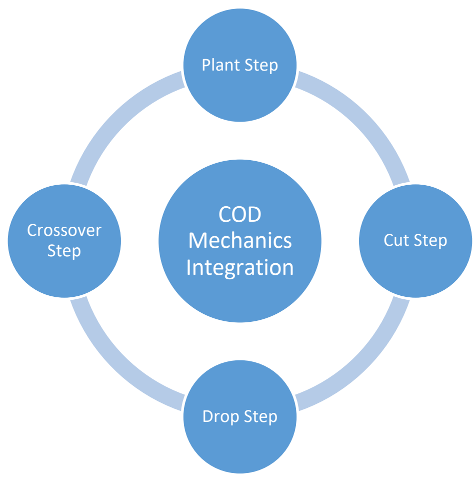

Figure 4. COD mechanics integration matrix.

Table 4. Agility training recommendation for youths[73,77,83,91].

Stages of Development	**Early Childhood (Neural Adaptation)**	**Pre-Pubertal**	**Circa-Pubertal**	**Circa-Pubertal – Late Adolescence**
Structure	Low	Low	Moderate	Highly
Main Objectives	FMS – Locomotion (run, skip & hop)	FMS – Exercise movement skills, locomotion, jump & land	COD mechanics & skills	RA
Intensity	Low	Low	Moderate	High
Rest Intervals	30 – 60 s	30 – 60 s	60 – 90 s	90 s
Training Frequency	2 – 3/ wk (non-consecutive days)			
Recovery (between sessions)	48 – 72 h (non-consecutive days)			

Metabolic Conditioning

Significance of the Metabolic Energy Systems

To meet the metabolic and neuromuscular demands of sport and ensure optimal performance, the body needs to constantly replenish energy in the form of Adenosine Triphosphate (ATP) for the working muscles[92]. Movement is fuelled by a simultaneous supply of energy via a combination of metabolic pathways (phosphagen, glycolytic, and oxidative systems). The primary source of energy is dependent on the intensity and duration of an action or activity (Table 5)[93,94].

Table 5. Energy systems and duration of exertion[94,95].

Primary Energy System	Duration of Exertion	Work: Rest
Phosphagen (Alactic)	1 s – 10 s	1:12 to 1:20
Fast Glycolysis (Lactic)	15 s – 30 s	1:3 to 1:5
Fast Glycolysis & Oxidative (Lactic & Aerobic)	1 min – 3 min	1:3 to 1:4
Oxidative (Aerobic)	More than 3 min	1:1 to 1:3

While every sport has different metabolic demands, there are similarities in application principles for programme design[95]. A needs analysis of the sport should be used as a reference when planning for metabolic conditioning. Similar to resistance training, the youth coach should ensure that metabolic programmes are individualised to the athlete's developmental stage, current fitness status, and level of sports involvement.

Effects of Growth and Maturation on Metabolic Energy Systems

The working capacity of the metabolic energy systems are influenced by various physiological and genetic factors such as muscle composition, gender, and age[10,96]. Particularly in youths, gender

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92 Morrison, S., Ward, P., & duManoir, G. R. (2017). Energy system development and load management through the rehabilitation and return to play process. *International journal of sports physical therapy*, *12*(4), 697–710.
93 Gastin P. B. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports medicine (Auckland, N.Z.)*, *31*(10), 725–741. https://doi.org/10.2165/00007256-200131100-00003
94 Haff, G. G., & Triplett, N. T. (Eds.). (2015). *Essentials of strength training and conditioning 4th edition*. Human kinetics.
95 Hoffman, J. (2011). *NSCA's Guide to Program Design*. Human Kinetics.
96 Bergeron, M. F., Mountjoy, M., Armstrong, N., Chia, M., Côté, J., Emery, C. A., Faigenbaum, A., Hall, G., Jr, Kriemler, S., Léglise, M., Malina, R. M., Pensgaard, A. M., Sanchez, A., Soligard, T., Sundgot-Borgen, J., van Mechelen, W., Weissensteiner, J. R., & Engebretsen, L. (2015). International Olympic Committee consensus statement on youth athletic development. *British journal of sports medicine*, *49*(13), 843–851. https://doi.org/10.1136/bjsports-2015-094962

differences may be more prominent after the adolescent growth spurt[97]. Similar to resistance training, there is a positive correlation between trainability of energy systems and maturation status with some degree of individual variation[98]. It has been proposed that metabolic endurance for children and early adolescent athletes should be developed actively throughout all stages of maturation[10,99]. Therefore, sport-specific programmes should include a component on metabolic endurance throughout all stages of development due to the concurrent opportunities to promote technical and physical development[99]. After skill competencies are established, the focus may then shift towards a heavier emphasis on metabolic conditioning to optimise athletic performance in adulthood.

Maximum VO_2 (VO_2 max)[96,100,101]

VO_2max refers to the measurement of the maximum rate of oxygen consumption during incremental exercise. It is a representation of cardiorespiratory fitness and endurance capacity in sport. Conflicting studies on the improvements of VO_2max pre-PHV exist. This could be attributed to the differences in the research participants' physical background and methods utilised. Nevertheless, it has been suggested that the maximum rate of development occurs near PHV. Due to the positive influence of growth and maturation on VO_2max, males tend to have higher VO_2max compared to females during and after adolescence.

Lactate Thresholds (LTs)[100]

LTs consist of thresholds 1 and 2 in the aerobic-anaerobic transition of the blood lactate curve. LT1 refers to the first rise in blood lactate concentrations above baseline levels during an incremental exercise while LT2 can be classified as a significant change in the gradient of the blood lactate curve[102]. Possessing higher LTs may indicate better endurance capacity to prevent the accumulation of blood lactate from exceeding the rate of lactate removal. Elite youth athletes have been reported to accumulate lower blood lactate at the same relative exercise intensity when compared to untrained young individuals[100].

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97 Geithner, C. A., Thomis, M. A., Vanden Eynde, B., Maes, H. H., Loos, R. J., Peeters, M., Claessens, A. L., Vlietinck, R., Malina, R. M., & Beunen, G. P. (2004). Growth in peak aerobic power during adolescence. *Medicine and science in sports and exercise*, *36*(9), 1616–1624. https://doi.org/10.1249/01.mss.0000139807.72229.41

98 Matos, N., & Winsley, R. J. (2007). Trainability of young athletes and overtraining. *Journal of sports science & medicine*, *6*(3), 353–367.

99 Harrison, C. B., Gill, N. D., Kinugasa, T., & Kilding, A. E. (2015). Development of Aerobic Fitness in Young Team Sport Athletes. *Sports medicine (Auckland, N.Z.)*, *45*(7), 969–983. https://doi.org/10.1007/s40279-015-0330-y

100 Armstrong, N., & Barker, A. (2011). Endurance training and elite young athletes. *Medicine and sport science, 56*, 59-83.

101 VO_2max is a measure of the maximum rate of oxygen consumption during incremental exercise. It is a representation of an athlete's cardiorespiratory fitness and endurance capacity in sport.

102 Faude, O., Kindermann, W., & Meyer, T. (2009). Lactate threshold concepts: how valid are they? *Sports medicine (Auckland, N.Z.)*, *39*(6), 469–490. https://doi.org/10.2165/00007256-200939060-00003

Recommended Guidelines for Metabolic Conditioning (Tables 6, 7)

Sampling Stage[10,99]

During the initial stages of learning, coaches are encouraged to expose the youth athlete to high sets of unstructured (randomised) repetitions. This methodology during sampling seeks to achieve technical proficiency and basic metabolic endurance while tapping on skill acquisition principles.

Specialisation Stage[10,99]

As the youth athlete specialises, the conditioning programme may evolve to replicate the metabolic needs of the sport. The inclusion of sport-specific situations (e.g. SSGs in football) may be part of a metabolic conditioning plan.

Investment Stage[10,99]

As the youth athlete progresses from proficiency to mastery in a sport, enhancing the metabolic capacity for performance to increase athletic competitiveness is an essential part of a periodised training plan.

Table 6. Metabolic endurance training recommendations[100,103,104].

Mode	Continuous and interval training using large muscle groups
Method	Cycling, running, swimming, circuit training & resistance training
Frequency	3 – 4/ wk
Total Work Duration	30 min – 1 h
Intensity	80 - 90% HR_{max}
Programme Length	Minimum of 12 weeks

Table 7. Strength-Power training recommendations[99,104].

Mode	High-intensity speed, power and strength training
Method	Cycling, running, swimming, circuit training & resistance training
Frequency	2/ wk
Total Work Duration	30 s – 4 min
Rest Methods	Active (60 - 70%) or passive

[103] Baquet, G., van Praagh, E., & Berthoin, S. (2003). Endurance training and aerobic fitness in young people. *Sports medicine (Auckland, N.Z.)*, *33*(15), 1127–1143. https://doi.org/10.2165/00007256-200333150-00004

[104] Mountjoy, M., Armstrong, N., Bizzini, L., Blimkie, C., Evans, J., Gerrard, D., ... & Van Mechelen, W. (2008). IOC consensus statement: "Training the elite child athlete". *British Journal of Sports Medicine*, *42*(3), 163-164.

Intensity	> 90% HR_{max}

Conclusion

This joint consensus statement by the NYSI and SSI provides evidence-based training recommendations to share best practices and inform sports coaches on the benefits and safety of S&C for youth athletes. The recommendations can be a useful physical preparation guide for competitive youth athletes during their period of growth and maturation. The appropriate use of it could conceivably allow for a seamless transition into their post-pubescent phase of training where there might be a potential increase in the physical and physiological demands of their sport. Below is a summary of this manuscript that signifies the position of NYSI and SSI:

1. S&C is safe and effective when performed under supervision by a well-qualified professional and is consistent with the needs, goals, and abilities of the youth athlete;
2. The training programme planned should consider maturational stage, training age, fundamental movement skills competency, technical proficiency, existing strength levels, and psychosocial factors;
3. Exercises prescribed should follow a sensible progression based on the athlete's movement competency and level of experience;
4. Coaches, parents, and teachers should acknowledge the potential immediate and long-term benefits of S&C for youth athletes on their physical development, health outcomes, and psychological well-being;
5. A well designed S&C programme is not only safe but may also reduce sports-related injury risk; and
6. An appropriate S&C programme can also elicit a noticeable improvement in neuromuscular adaptations and motor skills and hence, improve sports performance.