PROJECT H2grOw

The impact of growth & maturation on athlete development in swimming: Considerations for coaches, parents & swimmers.

swimming australia | THE UNIVERSITY OF SYDNEY

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Foreword

(Jacco Verhaeren)

Identifying and developing extraordinary athletic potential can be a tremendously exciting process and journey. The process typically involves a blend of coaching art, science, environment, systematic planning and luck. Throughout this resource, we'll guide you through a set out of fundamental elements associated with growth and maturation that impact our athletes in swimming. We also seek to do this to take steps toward creating a winning edge in elite sport.

As a coach, sometimes existing scientific data does not provide an adequate, effective and conclusive answers to all the questions. I, as a coach, was confronted with this problem when coaching swimmers through growth and maturation. I felt I had to develop my own experience and my own knowledge on training though maturational periods. Now with growing scientific interest, we can now utilise both data and expert insight to provide further guidance. Through the development of our Australian Swimming Framework (ASF), Swimming Australia (SA) partnered with The University of Sydney to enhance specific swimming research with particular reference to growth, maturation and the process of athlete development. During our initial meetings we were exposed to greater scientific knowledge in contexts, and about key considerations for managing developing athletes through their maturational years. This was the starting point for the development of this resource.

This research-informed guide aims to educate, helping coaches, parents and swimmers to be aware of growth and maturation, and how they can forward plan their exciting journey. If approached candidly, it supports coaches to determine an athlete's stage of development and the subsequent overall multidisciplinary training plan for the future years. We look forward to having you with us on the journey.

Jacco Verhaeren (National Head Coach)

Resource background:

(James Salter & Stephen Cobley)

Adolescence is a developmental life-stage in the young individual (or swimmer). Adolescence encompasses unprecedented changes in the body's musculoskeletal, cardiorespiratory and reproductive system physiology (Naughton, Farpour-Lambert, Carlson, Bradney, & Van Praagh, 2000) and with accompanying psychological changes. During adolescence, there are accelerations in linear growth and disequilibrium alterations to body composition, typified by the occurrence of puberty and maturation toward the adult state. As a developing athlete, these developmental changes can influence skill and performance development in diverse ways.

Sporting organisations across the globe are presently developing and implementing holistic long-term athlete frameworks that attempt to better support young athletes learn skills and develop performance capacities across and within adolescence. Similarly, Swimming Australia also considers it essential to fully understand an athlete's journey through adolescence, accompanied by growth and maturation. Likewise, Swimming Australia also considers it vitally important to support our coaches, parents and athletes by providing appropriate information that can potentially inform healthy approaches to developmentally navigate through the turbulent adolescent stage (Dorn, Dahl, Woodward, & Biro, 2006). Swimming Australia, therefore, perceives this resource and future research in this area as being an important step toward these goals. On this basis, the present resource has several purposes and aims.

Resource purposes & aims:

The primary purposes of this resource are to provide respective members of Swimming Australia (e.g., coaches; parents; swimmers) with a research-informed guide of growth and maturation, as related to swimming. The purpose is to help members establish a more comprehensive understanding of how growth and maturation affect various aspects of the developing swimmer. Based on resource content, a secondary purpose is to help Swimming Australia administrators, practitioners (e.g., coaches) and parents, identify strategies and methods that can help young developing swimmers to better negotiate the time periods associated with growth and maturation; thereby helping promote longer-term participation and performance development.

The present resource aims are to:

- summarise and explain the growth and maturation process.
- explain how growth and maturation relates and impacts various facets of swimming.
- help Swimming Australia members, in particular practitioners (i.e., coaches), identify how to better consider the potential influences of growth and maturation on the various facets of swimmer development.
- help Swimming Australia members, in particularly practitioners (i.e., coaches), identify strategies to mitigate against the possible less preferable outcomes influenced by growth and maturation.
- help Swimming Australia members identify strategies that promote longer-term inclusive participation and performance development beyond maturation and into adulthood.

1. Growth & maturation: A brief introductory overview

(Shaun Abbott & Stephen Cobley)

In the first two decades of life, notably the years associated with childhood and adolescence, the human body grows and changes substantially. Some of those most observable changes are associated with physical (somatic) body proportion change, reflecting growth. Height and body mass are common measures of such growth; though it should be acknowledged that physical growth encompasses multiple components, such as bone and muscle tissue growth as well as hormonal change. Growth is considered a continuous process with a predictable sequence of events until full adult maturity is attained at approximately 18-20 years of age for males, and two years earlier for females (16-18 years). Figures 1.1 and 1.2 provide an illustrative overview of growth across childhood and adolescence.

Figure 1.1: Illustration of normative accumulated height (cm) according to age and sex.

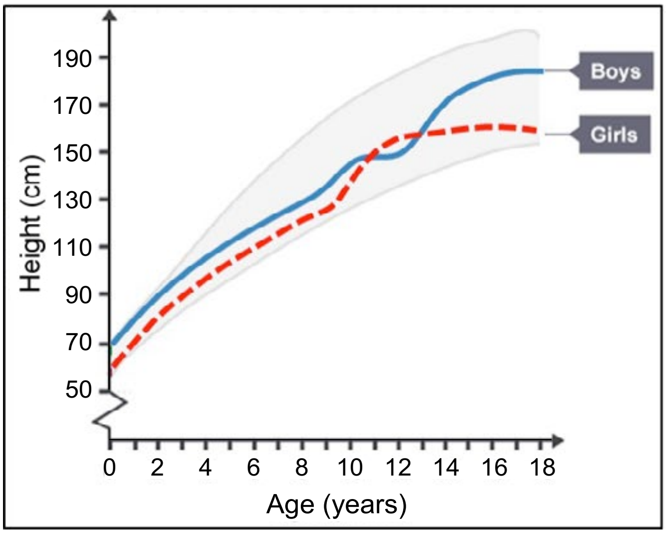


Figure 1.2: Overview of normative growth as shown by accumulated height (cm per year) according to age and sex.

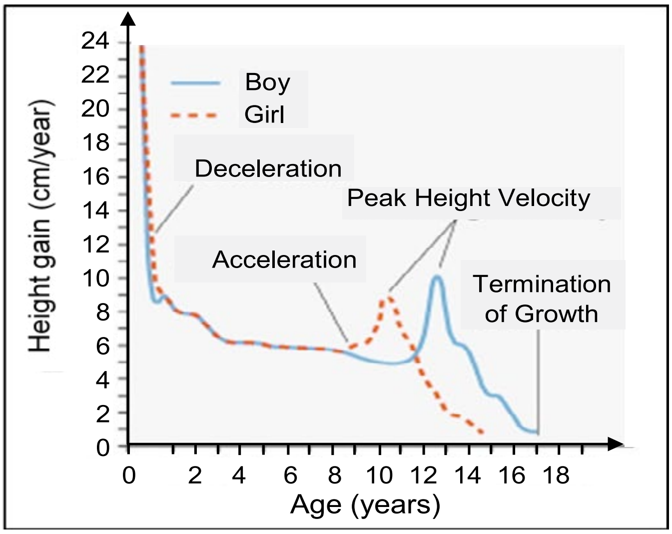


Figure 1.1 summarises the occurrence of height gain (cm) according to age (years old), while Figure 1.2 reflects accumulated height per year (cm/year) across childhood and adolescence. Note in both figures, the re-acceleration of height accumulation at approximately 10-11 (girls) and 12-13 years (boys) respectively. The re-accelerated time point of growth is also more commonly known as the time of puberty or maturation, where individual anthropometric and physical developments progressively transition into the adult mature state.

The process of maturation can occur somewhat individually in terms of *timing*; that is, when maturation-related events occur (e.g., first menstruation and age of growth spurt), and the *tempo* (or speed) of growth rates. The onset of maturation is affected by a range of factors including genetic (e.g., ethnicity), socioeconomic status, the physical environment (e.g., climate), stress and stressful life events, chronic illness, nutrition and diet (Kipke, 1999). However, there is no clear evidence to suggest that intensive sports training influences the timing of maturation (Malina, 1994). The maturity growth spurt can occur in females between 9.5-14.5 years of age; while it occurs later for boys, generally between 12-16 years, with an average of 14.4 years for normative populations (Stang & Story, 2005). During maturation, males generally gain between 10-30 cm in height, while females typically experience between 20-25 cm of height gain (Barnes, 1975). As the timing and tempo of the final growth spurt can vary substantially across individuals during maturation, it is common to observe individuals reporting different chronological age time-points of peak growth (see Figure 1.3).

Figure 1.3: Overview of 'early', 'average' and 'late maturity' status as reflected by accumulated height (cm per year) according to age in boys.

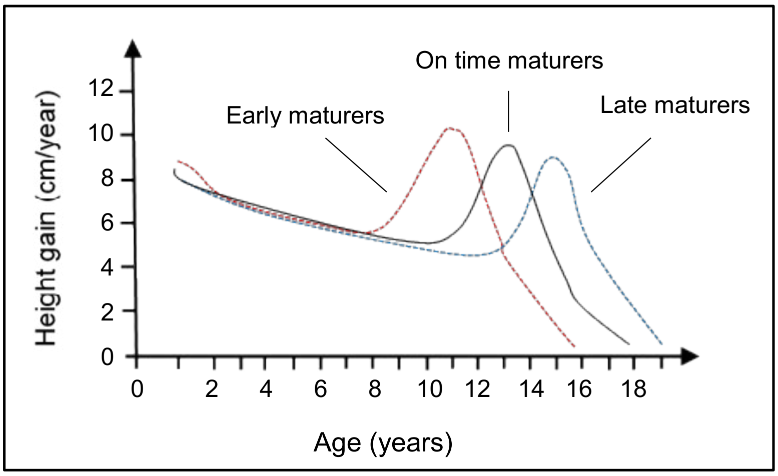
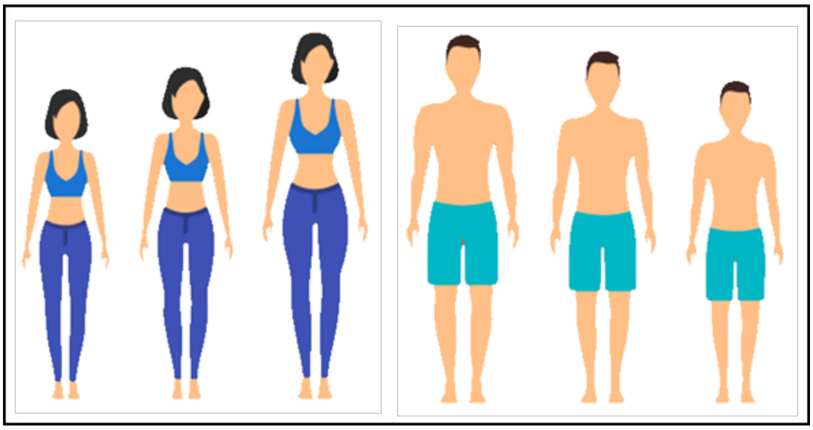


Figure 1.3 shows how an 'earlier maturer' is associated with a greater growth magnitude at earlier chronological ages compared to the 'average' or 'later maturer' (Tanner et al., 1966). Regardless of these development trends, overall adult height is not necessarily affected, as 'later maturers' may experience a longer pre-pubertal growing period which counter-balances their potentially less heightened final growth spurt relative to 'early maturers' (Hills et al., 2010).

It is also common to observe similar age-grouped sports participants (e.g., Under 13's) to be at different maturational stages. For example, similar aged peers at 13 years old, can vary by up to five years in terms of biological maturation (Kelly et al., 2014). Figure 1.4 illustrates the potential maturational variation that can exist within a chronological age-group during the maturational years.

Figure 1.4: Boys and girls of similar chronological age (e.g., 13 years old) but different stages of biological maturity.



As maturation timing and tempo varies across chronological age and between growing individuals, identifying the time-point of peak re-accelerated growth helps highlight the relative stage of maturation. This is known as Peak Height Velocity (PHV; see Figure 1.2) and is a milestone used to denote the 'high point of maturational growth' (Hills et al., 2010). Compared to other methods of determining maturation stage (e.g., secondary sex characteristics - Onat, 1975; and age at menarche - Tanner et al., 1975), PHV can practically estimate an individual's chronological age time-point of peak growth - whether presently there or not - and estimate the time-period away from PHV (Mirwald et al., 2002). PHV can also be used to estimate remaining growth (Sanders et al., 2017) and indirectly reflect skeletal maturity (McAteer et al., 2018).

In addition to PHV, other gender-specific body composition changes occur during maturation. Changes in fat-mass, fat-free mass (FFM) and body fat distribution typically follow a predictable sequence of events, with again marked inter-individual variability in the timing and tempo of change (Brown et al., 2017). Peak Weight Velocity (PWV), the accumulation of body mass in association with growth, usually lags 2-6 months behind PHV for males and females (Armstrong & McManus, 2011). At this time, body mass gain is predominantly from skeletal bone and muscle gain in males, while skeletal and fat-mass contribute most to female mass gain (Brown et al., 2017). Peak Strength Development (PSV), occurs typically 5-6 months after PWV or 1-1.5 years post-PHV. The lag of strength development behind PWV suggests that strength and power-based advantages in sport may not be observable until later adolescence (Armstrong & McManus, 2011). Thus, a 13-year-old male who has nearly completed their maturational growth spurt will likely enter subsequent maturity stages (e.g., PWV and PSV) earlier and experience significant muscular development and strength advantages. Similarly, an earlier developing female will experience initial advantages associated with the adolescent growth spurt compared to later maturers. However, they are also more likely to gain fat-mass earlier and report a higher fat-mass percentage as they transition into adulthood. This potentially can result in lower relative strength and altered sport-specific technique compared to leaner and later maturing females (Smoll & Smith, 2002), leading to potentially non-favourable effects on sporting performance.

How growth and maturation influences swimming performance

As growth and maturation processes is associated with body size change (e.g., height, arm length, body mass, muscle mass) and physical property (e.g., aerobic and anaerobic capacities) change, and these factors, in turn, predict swimming performance (Morais et al. 2017; Latt et al., 2009). Thus, growth and maturation are considered a key influential confounding factor on swimming performance, particularly during the years of junior and adolescent swimmer development. In junior swimming, performance at competitive events is determined by performance times relative to peers in annual-age group competition. However, if growth and maturational inter-individual variability are not considered, then age-group comparisons become problematic. For instance, a winning performance time in a given swimming stroke and distance at a junior/adolescent event may - to a greater or lesser extent - be influenced by advanced growth and maturation. To illustrate, refer to Figure 1.5 & 1.6.

Based on over 330+ boys (aged 8-18) and girls (aged 9-18) respectively who raced at particular regional, state and national competition events in the 2018-19 long-course season, the figures summarise the cross-sectional relationship between maturation status (distance from PHV; i.e., YPHV) and 100m Freestyle race times. Note the different time-points of heightened and lessened influence between boys and girls. Performance improvements are observed to accelerate (decline in seconds) when progressing toward and across PHV. Thereafter (i.e., 1 & 2 YPHV in boys and girls respectively), the influence of maturation begins to diminish. Generally speaking, similar trends occur in other swimming strokes and distances. Overall, figures 1.5 & 1.6 help explain how within annual-age groupings, swimmers with earlier and advanced maturation status will likely swim faster at a particular junior chronological age-group, while those who are 'later maturing' are less likely to

experience competition success at equivalent aged junior/adolescent swimming. At this point, caution is raised as these trends may all change in later chronological age-groups, where later maturing swimmers experience their accelerated benefits, 'closing the gap' and possibly even overtaking their early-maturing, depending on other factors (e.g., technical skill & biomechanical competency). Thus, for swimming coaches and practitioners, if not carefully considered, growth and maturation can in the short-term cloud subjective assessment and performance evaluation of junior swimmers, including the identification and selection of genuine swimming potential as opposed to those advanced in maturation status.

Figure 1.5: Relationship between maturation status & 100m Freestyle performance in boys (age 10-17 yrs).

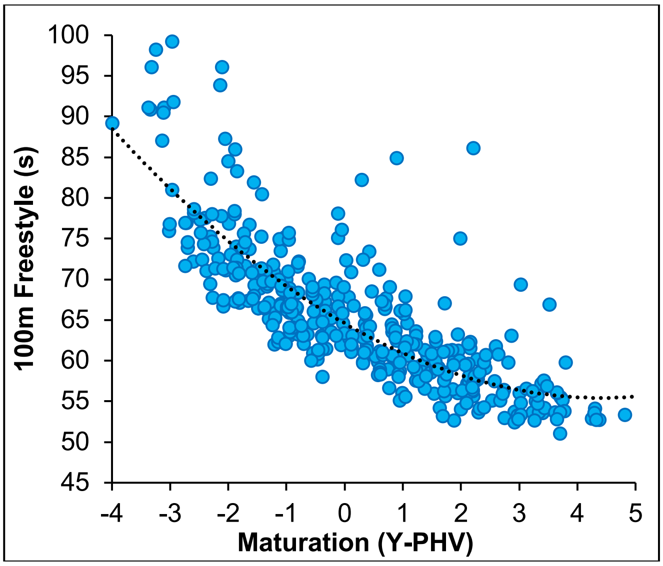
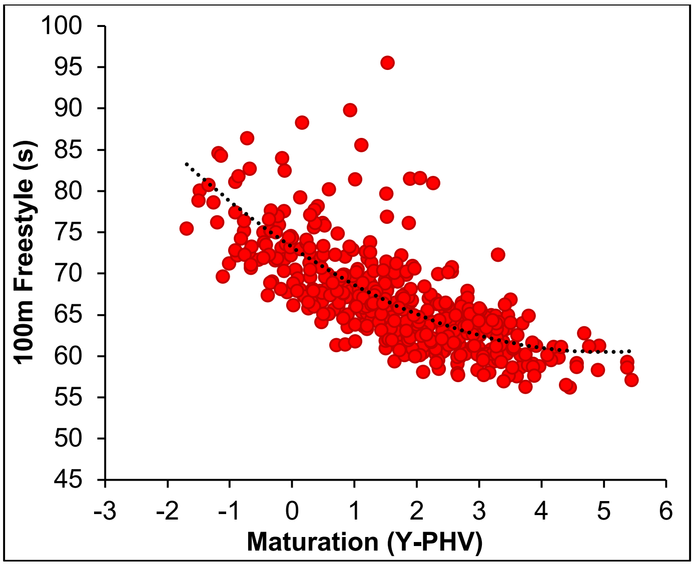


Figure 1.6: Relationship between maturation status & 100m Freestyle performance in girls (aged 10-17 yrs).



In the following sections, a more in-depth overview of how growth and maturation impacts various facets of swimming is explained. Further, from the varied perspectives taken within each section, how these impacts and influences should be considered are outlined. Attention to physiological development and change; injury; strength & conditioning, energetic and nutritional, as well as skill-acquisition and biomechanical facets is provided. Within and across each of these sections, considerations for practitioners, coaches, parents and swimmers are highlighted. These sections all align, attempting to place a greater spotlight on how to better holistically support growing and maturing swimmers in their development.

2. Growth & maturation with physiological considerations

(Sally Clark)

During growth and maturation, the human body undergoes significant physiological changes. There are large individual variations in the timing and magnitude of growth. Body size, body shape and body composition are all significant contributing factors to swimming performance. Early maturing athletes may experience early success due to growth-related advantages, so it is important for coaches to take an individual approach when it comes to designing a training plan and assessing the swimmers' progress throughout this period of rapid change. Technique and skills are an important aspect of a training program at any age; however, during periods of rapid growth, it is important to emphasise good stroke mechanics, since fitness development is more likely to come from growth-related changes.

Aerobic development

Aerobic capacity is the ability to generate energy via oxidative metabolism, which requires coordination of the respiratory and cardiovascular systems (Rowell, 1986). The development of aerobic fitness is fundamental in the success of any swimming program as it provides a platform for the swimmer to undertake work at higher intensities, recover from periods of increased work, and adequately prepare for multiple events at swimming competitions. Maximal oxygen uptake ($\dot{V}O_2$) is the most widely accepted measure of aerobic fitness and represents the combination of both the ability of the cardiovascular and respiratory systems to deliver oxygen to the contracting skeletal muscle and the ability for those muscles to consume oxygen (Wilmore & Costill, 1988).

The development of aerobic fitness is determined by growth-related changes to an individual’s central and peripheral cardiovascular system, muscular function, cellular capacity, body composition and metabolic capacity (Ford et al. 2011). A meta-analysis of several studies reports that between the ages of 8 and 16 years there is a gradual increase in $\dot{V}O_2$ peak (L/min) in relation to chronological age among boys and girls but the trend is not as consistent among girls (Armstrong & Welsman, 1994). When $\dot{V}O_2$ peak is expressed in relation to body mass (ml/kg/min) the difference between the sexes is more pronounced. The value of $\dot{V}O_2$ peak (ml/kg/min) for boys remains unchanged from 8-18 years. However, there is a decrease among girls for the same time period which is attributed to the boy’s greater muscle mass and haemoglobin concentration (Armstrong & Welsman, 1994).

Measuring $\dot{V}O_2$ in sports such as running, and cycling is relatively easy using laboratory-based ergometer tests. In swimming, collecting metabolic data poolside is challenging and the multidisciplinary nature of swimming in terms of different strokes is a further complication. Therefore, the assessment of aerobic capacity among swimmers is performed indirectly using progressive incremental swim tests (e.g., 7x200m). During the incremental test, heart rate and lactate responses to sub-maximal exercise are measured with the premise that these factors are sensitive indicators of endurance (Anderson et al., 2008; Pyne et al., 2001) and that the lactate responses are related to training-induced adaptations occurring within skeletal muscle (Foster et al.,1993).There have been several studies that have set out to determine if endurance training can improve aerobic capacity during periods of growth and maturation. Using changes in $\dot{V}O_2$ peak as a measure of increasing endurance performance the results have been equivocal (Naughton et al., 2000). Given we know that there are other indicators of aerobic capacity (e.g., delayed lactate threshold and an efficient economy of energy - Pate & Ward, 1996), using the progressive incremental test throughout growth and maturation may provide coaches and scientists with a better understanding of the individual's response to the training undertaken.

Aerobic conditioning is important at every stage of maturation and there is no evidence to suggest that sustained aerobic training for sport has any effect of attained stature, timing of Peak Height Velocity (PHV) and rate of growth in stature (Malina, 1994). In fact, Rowland (1996) reported that aerobic development is enhanced in the period prior to PHV and therefore is a valuable time-point for prioritisation of aerobic fitness training. Given this recommendation is based on cross-sectional studies, further longitudinal studies that map changes in aerobic capacity during growth and measure the influence of training concurrently are required (Ford et al., 2011). It is common practice to predominately train the aerobic energy system prior to maturation. The late-maturing swimmer will benefit from having a longer period to develop their aerobic capacity. However, it may not become evident until they are older. It is therefore important when organising squads that the biological age of the swimmer is considered to ensure individual progressions can be achieved to maintain longevity in the sport.

Anaerobic development

Anaerobic power is defined as the peak rate in which energy is produced via anaerobic metabolism. Anaerobic power is also difficult to measure directly and so is usually derived from measures of peak power measured during short all-out exercise (< 30 seconds; Osborne & Minahan, 2012). In swimming, anaerobic power may be measured by the ability to perform sprint activities over short duration (< 30s).

In addition to the rate at which energy can be produced, the total amount of energy that can be produced by the anaerobic energy systems is important for training and performance in swimming. Anaerobic capacity is defined as the maximal amount of adenosine triphosphate (ATP) resynthesised via anaerobic metabolism (by the whole organism) during a specific mode of short-duration maximal exercise (Green & Dawson, 1993). Anaerobic metabolism consists of two pathways. The first is called the phosphagen system which produces energy as a result of the breakdown of phosphocreatine to enable the reformation of ATP. The second pathway is through the degradation of glycogen or glucose to produce ATP in a process not requiring oxygen. This pathway is referred to as anaerobic glycolysis and results in the production of lactic acid (McArdle et al., 1991)

In general, children do not have well a developed anaerobic metabolic system, which has been demonstrated by lower blood lactate levels at peak $\dot{V}O_2$, and lower concentration of enzymes responsible for glycolysis, compared with un-trained male adults (Eriksson et al., 1973). Boys and girls show similar sprint speeds in their childhood, due to the rapid growth of the central nervous system (Ford et al., 2011). During puberty, the increase in muscle substrates and enzymes, along with developing muscle size and length improves speed immediately before and during adolescence (Ford et al., 2011) The first period of accelerated adaptation is between 7 and 9 years in both sexes, while the second window is around the age of 12 in girls, and 12-15 in boys (Ford et al., 2011), coinciding with maturational PHV.

Direct measurement of anaerobic metabolism is challenging because of the invasive nature of techniques (muscle biopsies) required. There is limited research performed using children and adolescence due to ethical and moral constraints (Naughton et al., 2000). Indirect measurements have been developed which include the 30 second Wingate Anaerobic Test (WAnT; Inbar et al., 1996; Weber et al., 2006) The WAnT examines both mean and peak power in an all-out effort lasting 30 seconds. Using the WAnT test, Falgairette et al., (1991) reported the highest power output (W/kg) and post-exercise lactate levels were not different between 6-8 and 9-10 year-old children but were significantly increased among 11-12 year-olds. The onset of puberty appears to be an important period in the development of anaerobic power and is likely a result of changes in body size, muscle mass and glycolytic capacity. Although there is a consensus that the aerobic system is the predominate system to train during growth and maturation, it has been reported that a 9-week high-intensity training program improved anaerobic power and capacity when performing the Wingate test among children (Rotstein et al., 1986). Such testing may be useful in a research setting, though in terms of swimming, coaches may perform tests such as 3x50m max effort swims and record the mean speed as well as the ‘drop-off’ between swim times as a useful indicator. Such testing may provide indicative information on anaerobic capacity and how well they may tolerate high-intensity swimming.

Physiological implications

Swimming performance during maturation is dependent on a range of physical, technical, and psychological variables. Early maturing boys are likely to exert performance advantages because of their increase in size and strength. This may not always be true for females because of the physique of a late-maturing female may be advantageous for swimming performance. The interaction between physical attributes and technical skills also cannot be forgotten. For instance, Zacca et al., (in press) determined the contribution of bioenergetics, technique, and anthropometric profiles on 400m performance among age-group swimmers over a 3-peak swimming season. They reported that the biggest contribution to performance was an improvement in technique, supported by improvements in aerobic fitness, and underlying growth and physical maturation. This study further supports the role of technique development and enhanced swimming efficiency in age-group swimmers, while developing a sound aerobic base.

During growth and maturation, because of the variability in the development of fitness characteristics, children may be disadvantaged on performance tests due to their maturity status, particularly when compared to chronological-age specific norms (Fiander, Jones, & Parker, 2013). The impact on performance changes is influenced by growth-related changes to an individual’s central nervous system, muscular function, cellular capacity, body composition and metabolic capabilities (Ford et al., 2011) To minimize these effects, or enhance them, coaches need to understand the factors during development that could account for constrained performance development relative to others, while focusing on facets of performance that could be improved in accordance with developmental ‘windows of opportunity’ (Fiander, Jones, & Parker, 2013; Jones, Hitchen, & Stratton, 2000), or those that can be developed irrespective of windows (e.g., technical skill and efficiency). Periodic testing using an identified test may prove most informative and useful. Though tracking individual swimmer development over time, and making appropriate developmental (e.g., maturation) stage comparisons may be most appropriate to inform swimmer development as well as selection and identification.

3. Growth & maturation with physiological change & injury considerations

(Peter Fricker & Ivan Hooper)

Optimal athletic development requires long periods of uninterrupted training. An injury at a critical time during the formative years of an athlete's career can have a very significant impact on athletic development. Grimmer et al., (2000) identified that 8% of Australian adolescents drop out of regular sporting activity annually due to injury, while Caine et al., (2003) found that 16% of the athletes dropping out of an elite sport apportioned this to an injury. These numbers highlight that injury, and its prevention, needs to be properly considered in relation to the development of an adolescent swimmer.

Growth, maturation and effects on individual tissues

As outlined in Section 1, the body undergoes significant change during the pubertal growth spurt. At a tissue level there is a relative decrease in joint and muscle flexibility (Micheli, 1983; Malina, 1974). Bones experience a relative decrease in strength and bone mineral density (Faulkner et al., 2006) and the cartilage that exists in joints during growth is less resilient to load than mature adult cartilage (O'Neill, 1988) with this being amplified by the pubertal hormones (McKay et al., 2016). These decreases in flexibility and strength of cartilage and bone are preceded by the increases in lean tissue mass (Jackowski et al., 2009), representing a period of increased risk where stronger muscles are pulling on weaker connections.

During this period there is a rapid change in the height and mass of limbs and this changes their moments of inertia. This changes coordination and the tensile forces across tendons and joints (Hawkins & Metheny, 2001). There is also a decrease in proprioception and neuromuscular control (Quatman-Yates, 2012). The consequence is a negative impact on swimming technique and efficiency, thereby increasing the load on tissues. There needs to be careful consideration of swimming volume during this period.

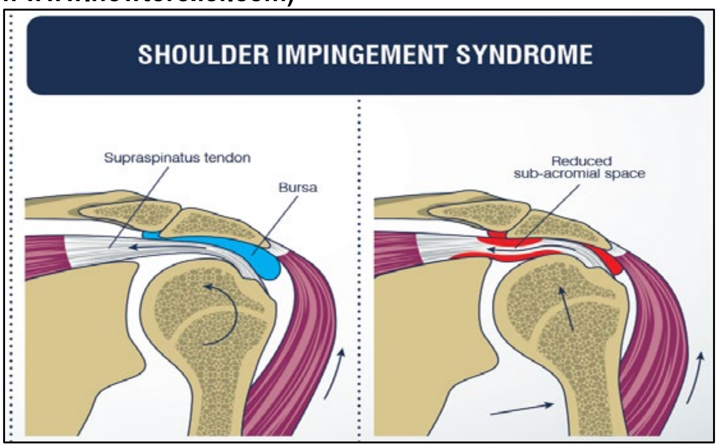
Tendons and overall tendon strength are responsive to the loads placed on them. In simple terms, they will respond to the strength of the muscle pulling on it. Tendon tissue takes much longer to develop compared to muscle tissue, but over time as a muscle gets stronger, the tendon will get stronger. If you consider the 1-2 year lag between PHV and PSV, it seems logical that peak tendon strength development may occur even later after the onset of puberty, and this needs to be considered.

Common developing swimmer injury: Shoulder

Shoulder pain is the most common presentation of injury in swimmers (Blanch, 2004; McMaster 1999; Abgarov, 2012) and can be seen affecting anywhere between 40%-90% of swimmers at any given time. Elite swimmers have been reported to use their shoulders through 2500 shoulder revolutions each day at training (Pink & Tibone, 2000). Research by Sein et al., (2010) demonstrated that in a population of 80 young elite swimmers, approximately 70% had tendinopathy in the rotator cuff muscles. Tendinopathy describes tendon damage involving overuse, microtears and collagen degeneration. The nature of swimming places the rotator cuff tendons into positions where they experience a mixture of tension, compression and shear. When this combines with elite training volumes, it can lead to structural changes in the tendons (Delbridge, Boettcher & Holt, 2019).

Fatigue of the rotator cuff (comprising the tendons of supraspinatus, infraspinatus, teres minor and subscapularis), the pectoral muscles and the muscles of the upper back may result in faulty mechanics around the shoulder joint, such that the soft tissues which insert onto the humeral head and upper humerus become injured – so-called microtrauma (Pink & Tibone, 2000). Impingement of the rotator cuff muscles under the coracoacromial arch (at the top of the shoulder) has been well described in the literature over the years, and research has demonstrated the factors contributing to this impingement related to a combination of stroke mechanics, overuse and/or fatigue of muscles and laxity of the ligaments of the shoulder joint, allowing abnormal movement of the head and subsequent shoulder instability (Wanivenhaus et al., 2012; see Figure 3.1 for an overview).

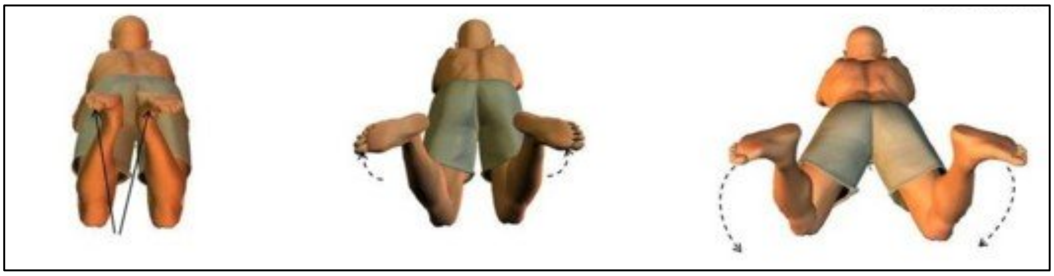
Figure 3.1: Shoulder impingement syndrome: A common injury in developing swimmers. (diagram from www.howtorelief.com)



Common developing swimmer injury: Knee

The knee is the second most often reported site of pain amongst high performing swimmers (Rodeo, 1999). Breaststroke swimmers are particularly at risk of knee pain, with one survey reporting 86% of 36 competitive breaststroke swimmers being affected on at least one occasion (Rovere & Nichols, 1985). Faulty kick technique, swimming volume, restricted hip mobility and reduced hip and adductor muscle strength are all contributing factors. Overuse is believed to be the main factor in knee pain, and because of the breaststroke swim technique (see Figure 3.2), the swimmer's knees are subjected to a repeated force which stresses the medial side of the knee in particular. The most common structures involved are the medial collateral ligament, patellofemoral joint and the adductor tendon.

Figure 3.2: Breaststroke swimming technique more likely associated with knee injury. (diagram from www.swim-teach.com)



In biomechanical terms, the stress on the knee is described as high valgus loads to the knee with hip adduction. Extreme hip abduction at kick initiation can be detrimental, with hip abduction angles at less than 37 degrees or greater than 42 degrees is associated with higher rates of knee injury (Viszolyi et al., 1987). Biomechanical analysis has also shown swimmers with medial knee pain have different whip kick patterns from those with no pain (Stulberg et al., 1980). Video analysis of breaststroke mechanics in swimmers with knee pain showed high angular velocities at the hip and knee, together with increased tibial rotation (Keskinen et al., 1980). Swimmers with medial patellar facet pain keep their hips in more abduction and show greater hip and knee flexion, while swimmers with medial collateral ligament pain de-rotated and plantarflexed the ankles as the knee extended. The kick in breaststroke stresses the medial collateral ligaments of the knee, the associated medial hamstring tendons and bursae (pes anserinus), hip flexors and adductors, particularly the adductor magnus and brevis (Rodeo, 1999).

Pain in the front of the knee (i.e., patellofemoral pain) can result from repetitive quadriceps muscle contraction as in 'the flutter-kick' in freestyle swimming, from push-off on the wall, or starts and turns when the knee is loaded in a flexed position (Rodeo, 1999). Similarly, pain from the patellar tendon may result from overuse in this way. Injury to the quadriceps with resultant wasting or weakness can affect patellofemoral tracking and predispose to anterior knee pain. Malalignment of the quadriceps extensor complex (from the thigh to below the knee) may also contribute to anterior knee pain (Wanivenhaus et al., 2012). Knee pain in swimmers correlates with the number of years of training, with training volume, with the performance level of the athlete and with increasing age (Rovere & Nichols, 1985). A significant increase in training load in younger athletes is a factor in swimming injuries (Wolf et al., 2009) and female swimmers may be more prone to injury generally (Sallis et al., 2001).

Common developing swimmer injury: Spine

Swimmers are also at risk of injury to the spine. Disc degeneration is seen more often in swimmers than non-athletes generally (Hangai et al., 2009) and this affects both males and females equally across all swimming strokes (Kaneoka et al., 2007). Factors in disc degeneration include training intensity, duration and distance (Kaneoka et al., 2007). Hyperextension of the spine in swimming, particularly so in breaststroke and butterfly (and exacerbated by fins, kickboards and pull buoys), loads the posterior elements of the spine and can result in spondylolysis (stress fracture) and spondylolisthesis (i.e., slipping forward of one vertebra on the vertebra below; Nyska et al., 2000). It is, therefore, important to pay attention to strength training in the gym. An inappropriate technique using either free weights or fixed weights can load the spine in extension or hyperextension, leading to injury. Similarly, using weights which overload the capacity to maintain muscle balance (agonists versus antagonists) can also result in injury.

Injury implications and recommendations

During adolescence addressing reductions in flexibility and strength around the shoulders, thoracic spine, hip and thigh is important, as is attention to correct swimming mechanics. Until these factors are optimised, the adolescent body will have a reduced tolerance to training load. Optimising these factors will also be governed by hormonal factors and normative biological growth, therefore necessitating time. It is unlikely that these particular physiological characteristics outlined can be “fast-tracked”; instead should be carefully assessed and monitored. To help prevent some of the common injuries highlighted, it makes logical sense to carefully structure strength training that may help develop more resilient swimmers. The challenge is how to achieve this while respecting the processes going on during the growth spurt.

In a large group of children aged 11-15 years old, Bostrum (2016) highlighted that time spent on resistance training with weights was actually also significantly associated with increased risk of injury. Further, there was no difference in injury risk for those children doing bodyweight-based resistance training (Bostrum, 2016). These findings suggest that the body's tissues and structures do not tolerate heavy loads during this developmental period. While not discounting the potential benefit from well-managed strength and conditioning, it perhaps makes sense to delay the exposure to heavy resistance training with weights until up to 1.5 years post PHV. Instead, strength training at this time-point may need to focus on 'lighter' and lower intensity work along with fundamental coordination training under the guidance of an experienced strength and conditioning coach.

Decisions about training volume and modalities of training during adolescence should be made relative to an athlete's growth spurt, not their chronological age. Both parents and coaches of adolescent athletes should regularly track an athlete's height and mass to help provide a practical estimation of where the athlete is relative to their growth spurt and help guide decisions regarding appropriate training. During the final growth spurt, there should be a high focus on flexibility, technical quality and movement efficiency. Once the athlete is far enough past PHV, the emphasis on strength can then increase. Finally, when tissue strength has developed, the athlete will be better able to handle increases in training volume, frequency and intensity etc.

To summarise, find below some common basic principles for injury prevention which are well established and should be fundamental to coaching practice.

- Develop 'good, appropriate' stroke technique which also minimises injury risk.
- Implement stretching and strengthening of the shoulder and upper back muscles together with the strengthening of core muscles of the low back and pelvis (i.e., to avoid excessive anterior pelvic tilt and lumbar lordosis)
- Develop muscle balance across joints to enable joint stability through ranges of motion.
- Implement and carefully monitor developmentally appropriate training loads.

If an injury does occur the principles of injury rehabilitation remain as follows:

- Early intervention is crucial to prevent further aggravation.
- Warm-up movements and activities should be encouraged to assess the severity of the injury. If pain settles with a warm-up, the session can proceed with careful monitoring. If not, the training load must be adjusted to avoid painful activity. A gradual, monitored return to previous training loads should be implemented. *Absolute rest is rarely indicated.*
- Beware of the use of hand paddles and pulling sets as they may excessively load the shoulder. Use kickboards and pull buoys judiciously to unload areas of injury.
- Dry-land training should be modified to promote pain-free graded increases in strength as recovery proceeds.
- If improvement is not apparent despite modified training, seek a medical review promptly and reassess.

4. Growth & maturation with strength & conditioning considerations

(Scott Dickinson)

Swimming - like the vast majority of sports - requires participants to execute multi-joint, multi-planar and multi-directional movements with varying degrees of velocity, force and stability (Giles, 2009). As such, the field of strength and conditioning seeks to ensure that any given swimmer is '*strong enough, fit enough & robust enough*' to meet and exceed the demands of training and competition. Strength and conditioning for junior and adolescent athletes generally have long been a divisive topic. Quite often, the debate revolves around questions such as "*When should children begin resistance training?"*; "*Should strength and conditioning be sport-specific in junior/adolescent ages?"*; and, *"When and how best can we develop the physical competencies of junior/adolescent athletes to make them ready to handle higher training and completion loads"*. Before considering these questions, it is important to have a clear understanding of some common strength and conditioning terminology. Table 4.1 provides a summary of key terms which will be used in this sub-section.

Table 4.1: A summary of key terms and their definitions used within strength & conditioning.

Key Term	Definition
Resistance Training	A wide range of activities that may have different or combinations of goals including improving general athletic qualities (e.g. motor control, strength, speed, power or size), sports preparation, rehabilitation or general fitness. Resistance training can include the use of any resistance modality such as body weight, resistance bands, machines, free weights, water or gravity.
Weight Training	A range of activities whereby external loads are used to perform resistance training. Weight training generally refers to the use of machines or free weights.
Weight Lifting	An Olympic sport in which the participant competes in two specific lifts; The Snatch as well as The Clean & Jerk.
Power Lifting	A sport in which participants competes in three events; Squat, Deadlift and Bench Press
Integrative Neuromuscular Training	A conceptual framework referring to a training program that incorporates a broad range of exercises including resistance training, stability, plyometrics, coordination and agility training. Exercises are progressive and are based on training age, maturation and competency. (Fleck & Kraemer, 2014; Myer, Lloyd, Brent, & Faigenbaum, 2013; Newton, 1999).

Role of strength & conditioning in swimming

The role of Strength & Conditioning (S&C) in swimming can be best summarised under the three-sub heading: (i) Injury prevention and general wellness; (ii) Development of general athleticism; (iii) Performance enhancement.

(i) Injury prevention and wellness

Swimming is a sport in which a high volume of sport-specific training is required to both perfect stroke technique as well as to develop the energy systems that are predictive of performance (Aspenes & Karlsen, 2012). As a result, swimmers are at high risk of developing shoulder and knee injuries (see section 3) due to developing muscle imbalances and fatigue which result in dysfunctional shoulder mechanics as well as degradation of the tendons from repetitive use. Therefore, it is imperative that muscles and tendons are strengthened and conditioned appropriately to tolerate high volume training and counteract muscle imbalances that can occur (Blanch, 2004; McMaster, 1999; Weldon III & Richardson, 2001). An appropriate S&C program will improve tendon strength, improve tissue resilience, reduce injury risk, as well as improve self-efficacy from an improved perceived capability to perform (Cook & Purdam, 2009; Fleck & Kraemer, 2014; Lloyd et al., 2014; Malone, Hughes, Doran, Collins, & Gabbett, 2019; Myer et al., 2011; Suchomel, Nimphius, & Stone, 2016).

(ii) Development of general athleticism

Strength & Conditioning training studies have consistently demonstrated improved motor performance, strength, power, endurance and flexibility as well as improved performance in general tasks such as endurance performance, running, jumping, changing direction and swimming (Behm, Faigenbaum, Falk, & Klentrou, 2008; Fleck & Kraemer, 2014; Lloyd et al., 2014; Stone et al., 2006; Suchomel et al., 2016). Exposure to a broad range of movement patterns early in the athlete's life may also result in an improved ability to refine and facilitate the execution of sport-specific movements later in life (Abernethy, Baker, & Côté, 2005; Myer et al., 2013). When children and adolescents are exposed to appropriate physical activity (including resistance training) before the onset of their growth spurt, they are likely to be more responsive to resistance training during and after their pubertal years. This suggests that neuromuscular exposure and safe/learning experiences in S&C may provide a foundational readiness to tolerate higher training volumes and intensities often required in later years, due to appropriate development (Myer et al., 2013).

(iii) Performance enhancement

Both general and specific forms of resistance training has been shown to improve swimming performance; increase stroke length; decrease stroke rate and increase tethered swimming force (Girold, Maurin, Dugue, Chatard, & Millet, 2007; Sadowski, Mastalerz, Gromisz, & Niźnikowski, 2012; Strzala & Tyka, 2009; Trappe & Pearson, 1994). Research has also demonstrated that stronger, more powerful swimmers perform better particularly in reference to sprint events (Aspenes, Kjendlie, Hoff, & Helgerud, 2009; Garrido et al., 2010; Girold et al., 2007). Additionally when executed properly, a well-developed S&C program helps to develop the physical robustness required not only to withstand the high volume of training, but also to improve work output including swimming stroke efficiency (Garcia-Pallares, Sanchez-Medina, Carrasco, Diaz, & Izquierdo, 2009; Izquierdo-Gabarren et al., 2010; Stone et al., 2006).

Within swimming, the successful execution of both 'starts & turns' which contributes to overall performance requires rapid lower body force production (West, Owen, Cunningham, Cook, & Kilduff, 2011). Relatedly, research has also shown that one key difference between elite and non-elite swimmers is lower body strength and power characteristics. Elite swimmers possess superior strength and power compared to non-elite, less physically developed and less experienced swimmers. Such differences are demonstrable across a range of metrics including the time taken to reach 15m; peak force; peak power; and relative peak power when measured both in dry-land and in pool-based testing (Jones, Pyne, Haff, & Newton, 2017). Thus, ensuring that lower body strength and power are considered within swimming development programs is important for performance success.

How to develop athletic potential: When, how and why?

To provide some clarity and direction around the issue of developing athletic qualities, Lloyd & Oliver (2012) proposed a framework called the Youth Physical Development Model (YPD). The model proposes and recommends that all physiological and skill component qualities can and should be trained across the athlete lifespan. They emphasise that a critical factor to consider is the quantity of work devoted to separate physical qualities and energy systems should be adapted to recognise the trainability of these systems as they change across childhood, adolescence and the onset of maturation as well as adulthood (see Figure 4.1).

Based on extensive research examining resistance training with children and adolescents. There are several common recommendations to support S&C practice with junior/adolescent athletes. These include the Australian Strength and Conditioning Association (ASCA), UK Strength & Conditioning

Association (UKSCA) and the National Strength & Conditioning Association (NSCA). These bodies have also developed position statements agreeing that:

- A *properly designed and appropriately supervised* resistance training program is safe for children.
- Children must be able to follow instructions and be able to handle the attentional demands of a training program.
- Children should be instructed by competent strength and conditioning coaches who can ensure that athletes utilise the correct technique when performing exercises. In Australia, this means that coaches should possess at least a Level 1 S&C Coaching Accreditation from the Australian Strength & Conditioning Association (ASCA).
- Appropriate activity, load and volume selection and progression should be ensured.
- For children (6 – 12 years) and first-stage youth athletes (12 – 15 years), bodyweight training and programs emphasising body and inter-limb coordination, stability and strength endurance should be the primary focus. Progression should only be made if and when athletes demonstrate movement competency at all levels; they are of appropriate training age, experience and capability; and, have appropriate supervision (Baker, 2009; Behm et al., 2008; Lloyd et al., 2014; Myer et al., 2013).

The rate of adaptation of different types of tissues varies greatly. Research has shown that 30-40% increases in strength can occur in as little as 8-20 weeks in preadolescent children (Faigenbaum et al., 2009; Faigenbaum et al., 1996; Granacher et al., 2011; Lloyd et al., 2014; Ramsay et al., 1990). Other studies have shown significant strength increases in as little as four weeks (Naclerio et al., 2013). These gains in children are largely attributable to neuromuscular adaptations and not in most part due to muscle hypertrophy (see Figure 4.2).

Figure 4.2. Contribution to strength response over time in youth athletes (Myer et al., 2013).

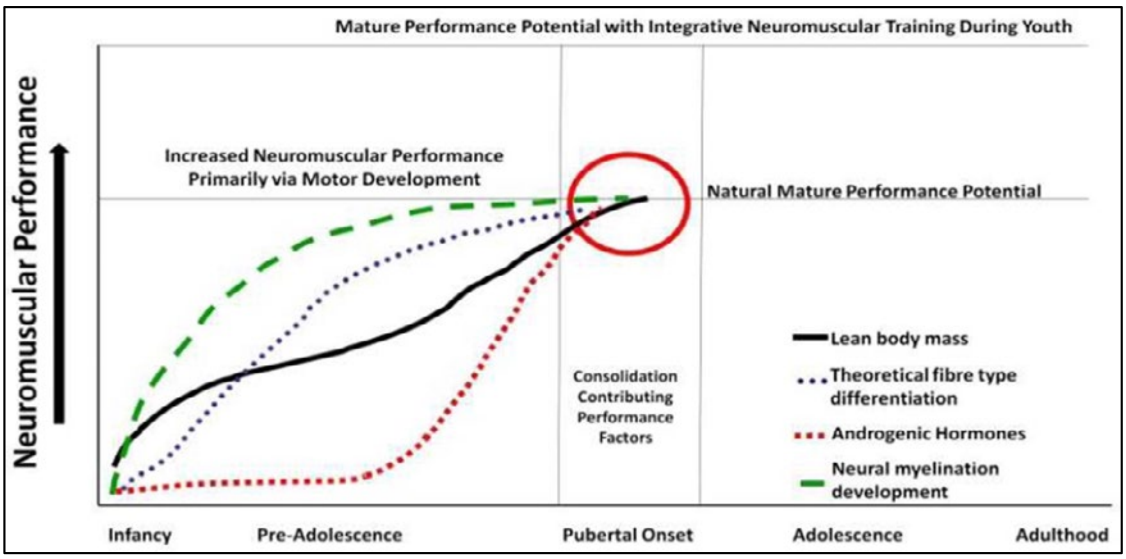


Figure 4.1: Adapted version of The Youth Physical Development Model for males and females (Lloyd & Oliver, 2012)

Chronological Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
Age Periods	Early Childhood			Middle Childhood							Adolescence									Adulthood
Growth Rate	Rapid Growth			Steady Growth							Adolescent Spurt				Decline in Growth Rate					
	Rapid Growth			Steady Growth						Adolescent Spurt					Decline in Growth Rate					
Training Adaptation	Predominantly Neural										Combination of Neural and Hormonal									
	Predominantly Neural									Combination of Neural and Hormonal										
Physical Qualities																				
Fundamental Movement Skills	High Importance							Low Importance			Low Importance									
	High Importance						Low Importance													
Sport Specific Skills	Low Importance							Moderate Importance			High Importance									
	Low Importance						Moderate Importance		High Importance											
Mobility	Low Importance			Moderate to High Importance							Low Importance									
	Low Importance			Moderate to High Importance					Low Importance											
Agility	Low Importance			High Importance												Moderate Importance				
	Low Importance			High Importance											Moderate Importance					
Speed	Low Importance			High Importance												Moderate Importance				
	Low Importance			High Importance											Moderate Importance					
Power	Low Importance			High Importance												High Importance				
	Low Importance			High Importance											Moderate Importance					
Strength	High Importance			High Importance												High Importance				
	High Importance			High Importance											Moderate Importance					
Hypertrophy	Low Importance													High Importance						Moderate Importance
	Low Importance										High Importance								Moderate Importance	
Endurance & Metabolic Conditioning	Low Importance																High Importance			
	Low Importance																High Importance			
Training Structure	Unstructured				Low Structure					Moderate Structure				High Structure				Very High Structure		

Figure notes: The colour blue refers to the trainability of males. The colour pink refers to the trainability of females. The colour green refers to attributes or qualities that are shared equally across the developmental pathway between males and females. Level of importance refers to significance of training these systems to maximise adaptation being sought at different stages.

While improvements in strength are part of the typical adaptations when undertaking an S&C program, it is important to understand that muscle strength increases at a faster rate than tendon strength. As such, a major focus of training should be to ensure that tendons capable of withstanding the increased forces that the muscle can produce to avoid injury. If a long-term approach is not undertaken to developing strength, the athlete can be predisposed to overuse/tendon injuries.

Specificity of training

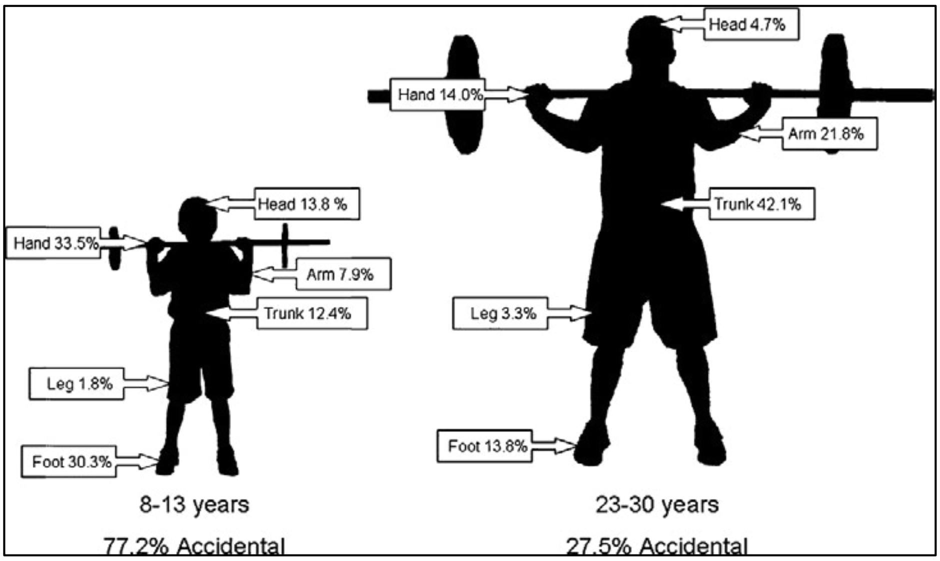
It is the position of Swimming Australia that resistance programs for children and adolescent swimmers should focus on providing a sound foundation in basic movement and coordination patterns rather than specialising too early in their swimming careers. Providing a good athletic foundation for children prior to the onset of puberty provides an excellent opportunity to increase their training age safely

Safety considerations: Dry-land training v weight training

The term 'dry-land training' is commonly used within the Swimming community to describe resistance training activities performed taking place on pool deck immediately prior to or post swimming training. It generally consists of trunk or 'core' training activities complimented by shoulder rotator cuff activities as well as some lower and upper body strength work. However, the label 'dry-land training' may in fact be better termed 'athletic development' because of the general and wide range of activities it incorporates outside the pool environment. In addition to the work performed on pool deck, it can refer to balance and coordination exercises, traditional strength training exercises performed in a gym, Pilates, Yoga or even additional conditioning work performed using bikes, rowers, etc. As referenced previously weight training can uses external loads to provide resistance. This is usually associated with dumbbells, barbells or machines as would normally be found in a gym.

The potential for injury during training is an important consideration in any training program. Whilst there have been associations between weight training and injuries (Boström et al., 2016), recent research indicates that *if weight training sessions are well structured and appropriately supervised by qualified and experienced personnel*, the incidence of injuries occurring is very low (between 0.17 - 0.05 per 100 participant hours). The same review reports that between 60 and 70% of injuries arise to children from weight training activities are injuries to the hand and foot (see Figure 4.3). These generally occur as a result of dropping weights or pinching extremities between weights or machines (Faigenbaum & Myer, 2010; Myer, Quatman, Khoury, Wall, & Hewett, 2009).

Figure 4.3: Percentage of weight training injuries per body part for 8-13 versus 23-30 year-olds (Myer et al., 2009)



It is also important to note that as with weight training, performing resistance training programs with bodyweight alone poses an injury risk if performed with incorrect technique. Exercises which result in improper shoulder, trunk or spine mechanics, exercises which reduce joint stability or overload muscle groups that are already fatigued from training also pose a risk of injury. The onset of the injury may not be as sudden or apparent as those commonly associated with weight training. However, they can be just as damaging to the development of any young swimmer.

Strength & conditioning implications

Taking the identified factors into consideration, a conservative approach should be employed when prescribing an S&C program for children and adolescent swimmers. All S&C programs should be delivered by experienced, ASCA qualified S&C coaches. S&C coaches should have a sound knowledge of exercise science as it applies to children and adolescents with a background in teaching youth athletes. The primary focus of any such program should be bodyweight exercises that emphasise technique, coordination, posture and joint stability (Baker, Mitchell, Boyle, Currell, & Currell, 2008; Lloyd et al., 2014; Lloyd & Oliver, 2012; Myer et al., 2013).

General guidelines:

Children aged 6-9 years of age

Strength & conditioning training in these age ranges should reflect a focus on the holistic development of fundamental movement skills, primarily with bodyweight exercises. There should be a heavy emphasis on movement competency. Training should incorporate a broad range of activities that encourage inter-limb coordination and provide athletes with fun and enjoyable exposure to developing athletic qualities. Loads should be limited to a weight that can be completed for more than 15 repetitions with perfect technique.

Children aged 9-12 years of age

As with the prior age-range, S&C training should reflect a focus on the holistic development of fundamental movement skills with primarily bodyweight activities. Some exposure to external resistances such as bands, appropriately weighted medicine balls, broomsticks, light dumbbells is appropriate, provided that the individual displays the required maturity and competency to progress. The correct technique should be emphasised at all times. Training should continue to incorporate a broad range of activities that encourage inter=limb coordination, providing athletes with fun and enjoyable exposure to developing athletic qualities. Loads should be limited to a weight that can be completed for between 10-15 repetitions with perfect technique.

Children aged 12-15 years of age

In this age-range, athletes are usually exposed to some form of structured resistance training for the first time. It is essential that the correct technique is emphasised, and that progression of the load is based upon a combination of the biological age, training age and competency of the athlete to execute the exercise correctly. It is appropriate at these ages to continue activities that incorporate inter-limb coordination and holistic development. However, the introduction of more traditional resistance exercises may also be appropriate, depending on the training age, biological age and competency of the athlete. Training loads should be limited to a weight that can be completed for between 8-15 repetitions with perfect technique.

It is emphasised that regardless of chronological age, if an athlete does not have a solid foundation in performing fundamental movement skills, priority should be placed upon developing skill and control prior to progressing to more complex tasks or higher loads. Biological (maturity) age, training age and technical competency should be the guiding factors in the decision-making process about whether or not to progress an athlete. For example, if a 14-year-old athlete demonstrates they are not able to correctly perform typical exercises, they should focus on required technical competency prior to progression. Any resistance exercise that incorporates more complex lifts should not be performed unless supervised and coached by a competent S&C coach (e.g., Level 2 ASCA S&C accreditation).

Any resistance training exercises should consist of appropriate selections from the following exercise streams:

- Body and spatial awareness / Balance and control
- Jumping / Hopping / Landing activities
- Squatting stream (double leg and single leg)
- Lunging stream
- Hinge stream
- Horizontal / Vertical Pushing stream
- Horizontal / Vertical Pulling stream
- Shoulder Function
- Bracing / Rotational stream
- Mobility / Flexibility stream

Desired criteria for progressions and some benchmarks for the various exercise streams are described in Table 4.2. For safety considerations, it is the position of Swimming Australia that all S&C (physical development) programs should be coached by appropriately qualified individuals, accreditation can be attained via The Australian Strength & Conditioning Association (ASCA).

Table 4.2: Adapted criteria for progression/benchmarks for various exercise streams. (adapted from Baker et al., 2008; Giles, 2009).

Stream	Test	6 – 9 Years of Age	9 – 12 Years of Age	12 – 15 Years of Age
Body / Spatial Awareness	Forward / Backward Roll	X	X	
	Forward / Backward Roll to Stand			X
	Log Roll in Streamline	X	X	X
Jumping / Hopping Stream	Double Leg Jump for Distance to Stick (no distortion of ankle, knee, hip, trunk)	>1.8m	>2.1m	>2.4m
Squatting Stream	Double Leg Squats (Hands behind head / Full range / Feet flat on floor)	>10		
	Overhead Squat (using broomstick) (>90 degrees)		>10	
	Single Leg Squat (>90 degrees)			>5
Lunging Stream	Lunge & Return (no distortion of ankle, knee, hip, trunk)	>5 each leg		
	Walking Lunge (no distortion of ankle, knee, hip, trunk)		>5 each leg	>10 each leg
Hinge Stream	Arabesque (no distortion of ankle, knee, hip, trunk)	>5 each leg		
	Single Leg Reverse Deadlift to Knee (using broomstick)		>5 each leg	
	Reverse Deadlift to Floor (40% BM)			>5
Horizontal Pushing	Push Ups (chest to floor)	>10	>20	>30
	Bench Press (+50%BM)			>10
Horizontal Pulling	Horizontal Pull Ups (feet on ground)	>5	>10	>15
	Bench Pull (+50% BM)			>10
Vertical Pulling	Chin Ups - Underhand Grip		>5	>10
Shoulder Function	Protraction / Retraction Elevation / Depression (good range, symmetrical & coordinated)	>5	>10	
	Alternate Protraction / Retraction Alternate Elevation / Depression (good range, symmetrical & coordinated)			>10 each arm
Bracing	4 Point Plank – Front & Side (elbows)	>60s	>90s	
	4 Point Plank – Front & Side (hands)			>120s
	Supine Plank	>60s	>90s	>120s
	Trunk Extension – Hands in Streamline			>60s
Rotation	Seated Rotation	>10cm	>20cm	>30cm
Flexibility / Mobility	Sit & Reach	0cm	>5cm	>10cm
	Combined Shoulder Elevation	>5cm	>10cm	>20cm

5. Growth & maturation with nutritional energetic considerations

(Greg Shaw)

Swimming performance is reliant on morphology and physique optimised for buoyancy, propulsion and reduced hydrodynamic drag. Additionally, a swimmer's physiology is developed through consistent overload and synthesis of new cellular pathways to deal with the increased training stimulus. The success of these developmental processes is often influenced heavily by dietary intake. In the young and growing swimmer, such nutrition intake is most commonly provided (or regulated) by significant others (family; coach), and the young swimmer often has little insight into their needs or requirements during and across stages of growth and maturation.

Energy requirements for maturing adolescent swimmers

During peak periods of growth, sufficient energy is required to support both the synthesis of new tissues and the training required to achieve athletic performance (Desbrow et al., 2014; Jeukendrup & Cronin, 2011). It is difficult to estimate the exact energy cost during this developmental period. However, the likely Daily Total Energy Expenditure (DTEE) is an accumulation of Resting Energy Expenditure (REE); the metabolic cost of daily-life often referred to as Non-Exercise Associated Thermogenesis (NEAT); the metabolic cost of absorbing and metabolising food (Thermic Effect of Food - TEF); the cost of growth and maturation (G&M); and, most variably the energy cost associated with associated swimming training and performance (Exercise Energy Expenditure-EEE). Overall, energy requirements can be considered the sum of:

$$DTEE = REE + NEAT + TEF + G\&M + EEE$$

The energy cost of resting metabolism, daily life activities and the thermic effect of food are likely similar between adults and growing adolescents in relation to metabolic tissue mass (i.e., skeletal muscle, bone, organ and brain mass). However, the major additional cost for adolescents during this period is the requirement for growth and development and completion of formal scheduled training.

The energy cost of synthesising new tissue

The energy requirements of growing new tissue consist of two parts. First, the energy of nutrients deposited in new tissues; and second, the metabolic energy cost of synthesising that new tissue (Torun, 2005). The energy deposited in growing tissue across the whole body in growing adolescents is small and has been reported to be ~8.6 kJ/gram of daily mass gain (Torun, 2005). However, this only accounts for the energy stored in synthesised tissue and don't take into consideration the fact that only a small percentage of ingested nutrients are integrated into new tissue. For instance, the energy stored in 1kg of muscle tissue could be accounted for as ~ 3,340 kJ in protein (muscle is only 20% protein), ~300-450 kJ in Glycogen (Glycogen is ~1% of muscle mass), and ~1,400 - 1,500 kJ in Fat (2-3%). However, only a small portion of ingested proteins make their way into skeletal muscle (approximately 10%; Stokes, Hector, Morton, McGlory, & Phillips, 2018). This would suggest that up to ten times the amount of dietary protein (2kg) is required to provide adequate substrate to grow 1kg of muscle and hence require an energy intake from protein of potentially 33,400 kJ. This energy requirement from dietary sources is likely less for other tissues such as adipose tissue deposited in females through adolescence. However, just attributing kJ/g of substrate accumulated is likely going to underestimate the true cost of tissue accretion especially that of lean muscle mass during growth and maturation. Further, the energy required to synthesis new tissue associated with the protein synthetic machinery is also significant and one that is likely distributed consistently over a day in exercising adolescents. The considerable cost of synthesis within cells is highly energy-dependent (Bier 1999) and could be as much as 20-25% of cellular energy metabolism (Browne & Proud, 2002) As stated previously, the energy cost of growth and maturation is complicated and an exact figure for the accretion of each tissue (bone, organ, muscle mass and connective tissue) is still not available. However, it is likely small in comparison to that associated with exercise energy expenditure of adolescent athletes.

As swimmers training through maturation, often undertaking training loads similar to those of their adult peers, it is important to understand how the energy requirements of maturing sub-elite swimmer's differ to their more developed peers. It is well established that sub-elite and junior swimmers are less technically proficient and therefore have a higher relative energy cost per meter swum when compared to more well-trained swimmers (Pyne & Sharp, 2014). This can be attributed to anthropometric (height, limb length), strength and technical capabilities (Pyne & Sharp, 2014). Therefore, for the same volume of training, adolescent less proficient swimmers likely have energy requirements up to 50% higher than their more elite training partners. With such significantly higher energy costs, it is perhaps unsurprising that parents of young swimmers who are growing and training frequently and intensely report anecdotal nutrition intakes well above those of senior elite swimmers completing the same absolute workload, especially in males. While energy requirements of adolescent swimmers are a unique combination of growth and development requirements, with additional energy required to complete the same training as their developed peer's, energy intakes are often sub-optimal due to poor organisation (self-regulation) skills and busy scholastic, social and other sporting activities.

Energy intakes of maturing swimmers

The energy intake of adolescent swimmers has often been reported as sub-optimal (e.g., Collins et al., 2012; Hawley & Williams, 1991; Martínez et al., 2011). Collins et al., (2012) reported that adolescent male and female swimmers had similar macro and micronutrient intakes to a matched group of non-athletes, even though swimmers exercised on average 8.6 h/wk. They reported energy intake of the swimmers was below requirement and had higher than recommended intakes of dietary fat, particularly saturated fats. Additionally, they had poor intakes of food groups beneficial to athletic training such as vegetables, fruits, grains and dairy foods (Collins et al., 2012). This data would suggest adolescent swimmers are influenced in their food choices more heavily by their non-athletic peer's food choices than eating specifically for their athletic training requirements.

In a group of New Zealand adolescent swimmers, an energy balance energy intake was reported at 13,000 kJ and 9,000 kJ in males and females respectively when completing ~6km per day, 6 days per week (Hawley & Williams, 1991). Males swimmers reported dietary carbohydrate intakes of 7.3 g/kg BM with protein intakes of 1.9 g/kg BM. Alternatively, female swimmers consumed intakes of 5.5 g/kg BM carbohydrate and 1.5g/kg BM protein over the same 4-day diet monitoring period (Hawley & Williams, 1991). Although these intakes appear adequate based on typical sport nutrition guidelines in the face of the relatively low energy intakes, the nutrient availability would be strained and likely inadequate to fuel high-level training over an extended period. By contrast, in a study of US elite adolescent swimmers participating in a national development camp, Berning & colleagues (1991) reported intakes of ~ 22,000 kJ for males and 15,000 kJ for females. At the time, the athletes were reported to have sub-optimal intakes of carbohydrate and protein, but more contemporary assessment would suggest intakes were adequate with carbohydrate (>7g/kg BM) and protein intakes at 2.14 and 1.84 g/kg BM for males and females respectively. This adequate intake is likely due to the camp structure where food availability and buffet eating possibly increased the dietary intake of the swimmers to adequate levels. To surmise, this body of research demonstrates that adolescent swimmers can consume enough energy and nutrients to fuel training as well as growth and maturation but require adequate knowledge and food availability to meet their training nutrition requirements.

Energy & nutrient availability: Consequences of getting it wrong

The consequence of inadequate dietary intake in relation to exercise energy expenditure has recently been highlighted in an IOC Consensus statement outlining a condition referred to as Relative Energy Deficiency in Sport (RED-S; Mountjoy et al., 2014). RED-S is a series of symptoms and conditions that are manifested as consequences of extended periods of Low Energy Availability (LEA). Energy availability is defined by the following definition:

Energy Availability = Energy Intake – Exercise Energy Expenditure

More practically, energy availability is the amount of energy left over ("available") after exercise has been accounted for to run all the necessary bodily functions. It highlights that when energy intake is insufficient and energy availability falls below a certain threshold, bodily functions reduce and in some instances stop (Nattiv et al., 2007). This reduced availability of nutrients, for typical function, is due to the body preferentially partitioning energy and nutrients for oxidation during and after exercise rather than for use in synthetic pathways. In adolescent athletes, prolonged and intensive periods of low energy availability may significantly delay puberty, increase menstrual irregularities, impair bone health, increase the risk of injury and impair immune function (Desbrow et al., 2014). Once exercise is completed, the body will use what is left to complete other bodily functions such as growth and development, reproductive and immune functions. For instance, if the body has oxidized most of the ingested amino acids from protein to provide energy for exercise, there is insufficient left-over to synthesis new proteins such as skeletal muscle (Areta et al., 2014) or connective tissue.

Interestingly, in a group of junior elite female swimmers, those who were in LEA had higher body fat levels, menstrual dysfunction, and saw 20% less training adaptation (-ve performance over 8 weeks) to those that were inadequate EA (Vanheest, Rodgers, Mahoney, & De Souza, 2014). Physical signs that a swimmer may not be meeting their requirements nutritionally can be prolonged fatigue, chronic mass loss, frequent illness and/or injury, periods of stagnant performance progression, delayed menarche or irregular menses and significant loss of vigour in adolescent males. As adolescence is a critical period for growth of skeletal muscle mass, connective tissue and bone mass and training adaptation, adequate energy and nutrient availability are essential to ensure these processes aren't impaired.

Macro-nutrient requirements

Carbohydrate for training energy requirements

Research into the substrate utilisation of adolescents versus adults suggests that at similar relative exercise intensities adolescents rely more heavily on oxidative metabolism than adults, and on exogenous sources of carbohydrate (Timmons, Bar-Or, & Riddell, 2003, 2007b). This is not always the case, especially for exogenous carbohydrate usage and potentially for variations in substrate utilisation by gender (Leites, Cunha, Chu, Meyer, & Timmons, 2016; Timmons, Bar-Or, & Riddell, 2007a), with girls using fat more as an energy source during submaximal exercise. Although conjecture remains around the glycolytic capabilities of adolescents (Haralambie, 1982), it is likely that adolescent exercise metabolisms are reflections of training status rather than pubertal development. Thus, for swimmers in growth and maturation, they are recommended to focus on consuming adequate quality carbohydrate-containing foods, aiming for intakes at the higher end of sports nutrition guidelines for training being undertaken (Shaw et al., 2014). For instance, a growing adolescent male swimmer will likely require carbohydrate intakes at the higher end of recommendations for a large portion of the training week (i.e., 6-8g/kg BM per day) to support training intensity and volumes. Females would also likely require higher carbohydrate intakes during adolescent years but likely less than males due to metabolic differences and lower absolute muscle masses (i.e., 4-7g/kg BM). Carbohydrate requirements will reduce after maturation as swimmers become more metabolically adapted to utilise fat at higher intensities and become more technically proficient further enhancing metabolic efficiencies. Adolescent swimmers should focus on intakes of a wide variety of carbohydrate-containing foods specifically quality wholegrain breads and cereals, dairy products, fruits and vegetables.

Protein requirements for growth and maturation

Protein requirements of adolescent swimmers is an accumulation of general health requirements, typical sport requirements and additional intake for synthesis of new tissue that occurs during maturation. Typical swimming sports nutrition guidelines suggest protein intakes between 1.5-2.0 g/kg per day are sufficient (Shaw et al., 2014). These recommendations are double the RDI's recommended for adolescents in Australia (NHMRC Australia, 2006). Typically, dietary protein intakes of adolescent swimmers fall within the range of 1.5-2.0 g/kg BM, suggesting total protein intake is sufficient for training, growth and development (Collins et al., 2012; Hawley & Williams, 1991). Where adolescent swimmers may require specific attention is related to the type, timing and distribution of dietary proteins over a training day (Desbrow et al., 2014). Protein intake should come from high-quality proteins high in essential amino acids necessary for growth and development. These include lean animal proteins, dairy products, nuts, seeds, legumes and other quality vegetarian protein sources. Anecdotally, adolescent swimmers typically consume protein intakes in large portions, mostly at lunch and dinner. Although these likely supplies adequate protein daily, more contemporary protein recommendations would suggest moderate protein serves (> 20g) distributed across the entire day are more beneficial for muscle tissue growth and development (Schoenfeld & Aragon, 2018).

When considered together, such information suggests that protein intake from quality dietary sources spread over a training day are sufficient to meet requirements and supplemental support is likely unnecessary. Supplemental protein sources such as a whey protein may be beneficial when access to quality protein foods is not convenient. However, whey protein may not be required if quality protein foods are available soon after exercise (<1h).

Dietary fat requirements for training and development

Dietary fats are essential to optimal growth and development, particularly the supply of essential fatty acids and fat-soluble vitamins. Typically, dietary fat recommendations are focused on the restriction of dietary intakes, especially during periods of body composition manipulation where adiposity reduction is the focus. Adolescent athletes have previously been reported to have high dietary fat intakes from inappropriate sources (Collins et al., 2012). However, this is likely a reflection of societal dietary patterns. The quality and quantity of dietary fat intake should be the focus of adolescent swimmers. During periods of high training volume (>70km/wk) when energy requirements increase above appetite and food availability, adolescent swimmers are encouraged to increase their dietary fat intake to help support energy requirements and minimise the incidence of LEA. Education for adolescent swimmers should focus on the intake of quality oils and fat, specifically the consumption of fatty fish, nuts, seeds and the use of monounsaturated and polyunsaturated oils in cooking to help improve dietary fat intake (Philippou, Middleton, Pistos, Andreou & Petrou, 2017).

Micronutrient requirements

Although micronutrients such as vitamins, minerals, phytochemicals and other bioactive food components are essential for growth and maturation, the exact additional demand needed for both maturation and training has not been established. In senior athletic populations, it is well established that supplemental intakes of vitamins and minerals are *not* required to support training (Rodriguez, Di Marco, Langley, & DiMarco, 2009). Athletic diets focused on meeting energy and macronutrient requirements from whole foods are capable of providing sufficient micronutrients to support additional requirements for training. Nutrients that may be of additional requirement include calcium, iron and B-vitamins (Desbrow et al., 2014; Woolf & Manore, 2006). Although requirements may be compromised in energy and food restrictive states, swimmers who focus on the consumption of a variety of quality foods can meet their requirements through food alone (Petersen et al., 2006). Adolescent swimmers should be encouraged where possible to eat a wide variety of foods. When increasing macronutrient intakes to meet increasing training demands, colourful fruits and vegetables should be increased proportionally to ensure adequate micronutrient availability.

Nutrition knowledge and food literacy

Dietary knowledge in talented adolescent swimmers may be insufficient to undertake the required consistent sports nutrition practices outlined above within a daily training environment. Although junior elite swimmers are often exposed regularly to nutrition education sessions, their general and sports-specific knowledge is often poor and no more advanced than school level education messages (Shaw, unpublished data). Structured education programs focused on educating both parents and athletes on food quality and general healthy nutrition practices have been shown to improve the dietary intake of swimmers (Philippou et al., 2017). The success of the adolescent swimmer at developing along a performance trajectory is reliant on their ability to meet their often changing energy and nutrient requirements. This takes significant nutrition knowledge and food literacy (Shaw, Boyd, Burke, & Koivisto, 2014). Nutrition education should follow a well-formulated education pathway moving from whole food sports specific focus to more detailed nutrient manipulation targeted at driving training adaptation. As the major focus of adolescent swimmers is to absorb the training load adequately and adapt during time-points of heightened growth and development, programs and educators should work with parents and swimmers to ensure sufficient knowledge and skill is developed to provide adequate energy and nutrients in both a convenient and appealing form.

Nutritional and energetic implications

Understanding the changing energy requirements of training from large volume to high-intensity swimming training during growth and development phases is key to optimal maturation. Generalised energy intake and macronutrient guidelines can be misleading due to the extreme variability in requirements of adolescent swimmers. For instance, a 50kg female with 20% body fat on a day off may only require ~9000 kJ, compared to 75kg, male with less than 10% body fat training 15km per day of intense training may require up to 30,000 kJ or more particularly if approaching peak height velocity. Failure to adequately meet energy requirements, particularly during intense training periods, can lead to significant changes in body composition; insufficient muscle mass and connective tissue development; increased incidence of menstrual dysfunction; and increased risk of illness and injury. On this basis, swimmers and parents should work with coaches to monitor and measure changes in training loads, fatigue, sleep, growth and development, and performance and adapt accordingly to help ensure nutrient requirements are met. A focus should be on consuming whole foods, especially quality carbohydrate-containing foods. Carbohydrate intake should be matched to the requirement as per typical adult sport nutrition guidelines. Females likely require less total energy, and carbohydrate due to lower muscle mass, improved swimming efficiency and differing exercise oxidative capacity. Education programs should focus on educating parents on ensuring adequate quality food is provided to swimmers at convenient times and in appealing forms.

6. Growth & maturation with skill-acquisition considerations

(Damian Farrow)

Based on the known changes in growth and maturation during childhood and adolescence, guidelines can be offered related to the skill acquisition process in swimming. This section is divided into four sub-components. First, a brief overview of skill acquisition is provided, followed by each key stage of maturation being considered as its own sub-component (i.e., pre-maturation; maturation and post-maturation). For each sub-component, key recommendations for each stage of development are discussed with reference to contemporary skill acquisition literature.

Skill-acquisition: An overview

Skill acquisition is a critical element in the development of swimming performance. It considers how a swimmer learns new or refines existing, movement patterns. Skill acquisition is predominantly concerned with understanding how a learner most effectively uses the many different sources of information available to them (e.g., sight, touch, feel, coach instruction, feedback technologies etc…) to coordinate and enhance their movement effectiveness. Skill acquisition scientists have been able to document strategies for the planning and design of practice (training) as well as the instructional approaches used by coaches/teachers that maximise the acquisition of sports-specific skills. They have also dispelled some myths about how skills are best learned (such as the notion of the need for perfect practice) and importantly provide growth-related recommendations for skill development (Chow, Davids, Button & Renshaw, 2016; Farrow, Baker & MacMahon, 2013). These evidence-based strategies and myths will be discussed in the sections that follow.

Pre-maturation and skill-acquisition

Consistent with the ever-expanding talent development literature that recommends sampling a wide variety of sports during the pre-maturation years rather than specialising in one sport (Côté, Lidor & Hackfort, 2009; Bergeron et al. 2015), skill acquisition at the pre-maturation stage should also be *diversified* in approach. Obviously, it's the child and their parent's decision as to whether the child solely focuses on swimming or participates in a variety of sports. But contemporary thinking highlights that engaging in more than one sport has advantages, particularly in regards to sustaining longer-term motivation and engagement in the sport; reducing the likelihood of overuse injuries; and, providing a broader base of skill movement experiences that will ultimately afford the child greater movement literacy when they do elect to specialise in a particular sport (Côté, Baker & Abernethy, 2007). Further, positive transfer of learning from one context to another can be strategically planned, if the child is encouraged to participate in a sport that demands similar movement qualities to swimming such as gymnastics (e.g., Oppici et al. 2018).

If sampling more than just swimming is not considered a viable option, then even within the sport of swimming diversification of movement experiences is critical to skill acquisition. The child should be focused on developing a broad variety of swimming skills. These include learning how to scull and propel themselves in the water; practicing all strokes and swimming in a variety of contexts (pool, open water, water polo, surf etc…) to identify and be able to adapt skills to the different contexts. The coaching approach should be one that fosters practice conditions where swimmers learn to discover and understand movement patterns that satisfy a particular task goal. Importantly, it needs to be recognised there is more than one way to swim efficiently, and so children at the pre-maturation stage should not be forced to adopt one rigid movement pattern. This perspective of allowing the swimmer to find a movement pattern that works for them rather than being required to fit some "perfect model" is a good example of contemporary theory challenging a myth of swim coaching. There are multiple examples of successful performers adopting quite different swim techniques to achieve their task goal i.e. swimming fast. Therefore it is recommended coaches set practice challenges where pre-maturation swimmers need to understand the basic concepts of propulsion and drag and develop movement solutions to enhance propulsion and reduce drag. For example, asking a child to demonstrate how many different ways they can push off the wall; and, asking them to identify the method that got them to travel further or faster etc are all important coaching strategies for skill acquisition and swimmer development at this stage.

Peak-growth in maturation and skill acquisition

As a young swimmer enters peak growth and maturation (or puberty onset), it is likely that they will begin to narrow down the range of strokes they will practice. This is also a time usually accompanied by increases in training load (i.e., volume, intensity etc). This is also a critical stage in skill acquisition terms. As described earlier, maturation is the stage when PHV occurs, followed by peak mass and peak strength development. These changes have a significant impact on the level of coordinative control in swimmers and obviously occur at different age-time points for individuals (and is typically earlier for females). Such development also makes a coach's role more challenging to ensure individualised training prescription is provided (Renshaw, 2010).

It is important for coaches and parents to note when the maturation stage occurs, it is also a time of significant physiological, mental and social load. While there will be all manner of individualised responses to maturation, in general when adolescents are experiencing a growth spurt (noting they have many brief rapid spurts), skill acquisition is more difficult relative to a period when development is more stable (Pangrazi, 2004). Often, swimmers like other young athletes may experience a period of lower and more variable movement control (or poorer coordination) as the swimmer struggles to harness their new segment lengths, mass and force. Not surprisingly, the physiological and metabolic load the swimmer experiences are higher than it may have been for the same training set/stroke at the pre-maturations stage. As a consequence, careful coach observation and consideration of impact from growth and maturation on skill-acquisition are required at this stage. The coach may observe, on the one hand, beneficial strength gains, but on the other also observe skill plateauing or movement inefficiencies. Related to the latter, and the possibility of increased injury risk, coaches may need to adjust training loads (i.e., usually a decrease), while a swimmer progresses through re-accelerated growth. Equally though, when the growth spurt is complete, this is a cue to ensure the swimmer re-tunes their movement patterns through skill targeted practice (Renshaw, 2010). For example, hand span may have increased as well as relative strength making the swimmers catch more effective than it was previously, which may then alter stroke rate which in turn may alter race tactics.

At the peak-growth maturation stage, the coaching approach needs to assess and allow for these significant changes. It is a stage where the coach should not be overly focused on trying to change the “technique” of the swimmer, given the movement pattern they are observing is simply a transitional phase and the coordination of the swimmer will continue to evolve. A more normative skill development rate will return post-PHV; hence why it is important for the coach to be aware of their athlete’s growth rates, so they know when it is timely to recommence skill-focused practice.

Post-maturation and skill-acquisition

Post-maturation is the stage when it is typical for a swimmer to narrow their focus onto a primary stroke or event. With accelerated growth now complete and relatively slower progression to the adult mature state occurring, the swimmer is now more physically able to complete more focused and demanding skill training in terms of training specificity, progression and overload (Farrow & Robertson, 2016). While movement pattern refinement will still be a focus and commonplace for most swimmers, the swimmer at this stage should not be required to embark on large technical changes, if their pre and maturational years have been appropriately planned.

There are several fundamental skill acquisition principles that should be present at this stage of development. The first is *specificity*. In simple terms, coaches should question the value of the drills they prescribe their swimmers. Often practice is isolated into parts and in turn transfer back to the full stroke is reduced. For example, what is the value of completing the single-arm drill? While the logic of such a drill may centre on enhancing breathing technique or body alignment the specificity principle would question the value of such practice. This is another example where the value of particular drills takes a mythical status despite any evidence of their value. In simple terms, swimmers should be encouraged to maintain the full coordination pattern of a stroke as a whole and simplify or exaggerate sub-components through strategies such as hand paddles, resistance bands etc.

At this stage of development, *progression* should be a focus. This entails continually challenging the swimmer through progressively increasing the challenge of a skill session or practice drill. If it is observed a swimmer is repeatedly handling a particular challenge, this is the cue for a coach to increase the challenge whether that is by altering a stroke rate, count, time or some other means. One particularly effective practice strategy is known as practice variability. As the name suggests practice becomes variable rather than repetitive in nature when implementing variable practice. For example, forcing the swimmer to switch between different practice drills or strokes every 100m rather than doing much longer blocks of a skill or drill before switching. While such practice may appear to disrupt the swimmer's immediate performance, it is well-established that it will enhance the longer-term retention and performance of those skills as a consequence.

These progressive increases in challenge are what is referred to as *overload*, and is fundamental to enhancing skill acquisition. Analogous to weight training in a gym, swimmers need to have their skill demands constantly monitored and when success occurs regularly, an overload in challenge needs to be presented. We don't lift the same amount of weight or complete the same repetitions week after week in a gym context, and similarly, when developing skill we also need to continually challenge the swimmer's skills.

While developmental changes will still occur, such as continued increases in strength, this is more likely to be due to specific training adaptation rather than growth. Consequently, coaches can expect the athlete to have established a preferred movement pattern/stroke which can then be challenged with increasing demands including changes in pace, rate, pressure and fatigue levels to ascertain the skill level of the athlete.

Skill-acquisition implications

Clearly maturation has a significant impact on the capacity of a swimmer to develop and refine their swimming skill. In simple terms, it is suggested in the early stages of development a less prescriptive, more exploratory approach be adopted by coaches of young swimmers so that they can find an approach that works for them. Peak maturation is a time when skills will be impacted significantly by growth and hence coaches and parents need to be aware of the increased physiological and psychological costs on a swimmer's skill at this time. The post maturation period is where more systematic practice approaches can be implemented that are focused on performance enhancement. In particular, a focus should be on creating practice activities that closely reflect the specific demands of swimming. Further progression through overload is critical to ensuring development (and in turn performance) doesn't stagnate. There are a host of skill practice strategies designed to assist with this aim. Coaches and parents are encouraged to understand how variability in practice is particularly advantageous to skill acquisition.

7. Growth & maturation with biomechanical considerations

(Marc Elipot, Cecilia Brophy-Williams & Gina Sacilotto)

The assessment of a swimmer's skills across phases of growth and maturation is a challenge for any sports scientist, coach or parent sport. To further effectively monitor and track swimmers requires a good understanding of the fundamental biomechanical mechanisms while taking into consideration individual differences in terms of their anatomical, physiological and psychological maturation. For instance, some fundamental swimming skills will potentially only be attained when a particular stage of maturation is reached (e.g., level of force/power; intellectualisation of some technical aspects, joints ranges of motion etc). Given these concerns, the following sub-section provides key information on the main skill characteristics to observe in developing swimmers, enabling a more informed outlook on biomechanically appropriate technique.

Evolution of key determinants in swimming performance

From a biomechanical perspective, swimming speed can be considered as a product of a swimmer's stroke rate and length. Stroke rate is defined as the number of strokes or cycles per minute, while stroke length is the distance covered by the swimmer during a full-cycle (i.e., hand entry to subsequent hand entry on the same side of the body). These two basic parameters are the most widely used determinants to predict swimming performance. However, a lesser-known parameter, stroke index, also provides insight. Stroke index is defined as the average velocity and average stroke length over a particular section of a race and can be utilised as an indicator of swimming efficiency. Recent multidisciplinary and longitudinal studies of young swimmers have analysed the relative importance of numerous factors on swim performance. Collectively, these studies evidence that stroke index, stroke rate and stroke length are the best predictors of 400m swim performance in young female (aged 12-14 years) and male swimmers (aged 13-15 years; Latt et al., 2009a; Latt et al., 2009b). The notable improvement of swim performance that occurred over time was related to both the swimmers anthropometric and physiological development (i.e., height; hormone production; maximal oxygen consumption) and biomechanical swimming stroke index. Furthermore, stroke index improvement was not only related to growth and maturation but was also developed independently as a learned skill. Thus, developing technical efficiency in strokes during growth and maturational time-points was important to achieving a higher level of performance.

In alignment with prior findings, Mezzaroba et al., (2014) analysed the performances of swimmers, aged from 10-17 years old, competing in the 100m, 200m and 400m Freestyle. They also demonstrated that the improvement of stroke efficiency (examined via stroke index) was a key factor in the development of swim speed during growth. Within the study, they reported: (1) for a specific distance, the stroke rate remained constant within an age bracket, whilst the stroke index and stroke length increased considerably. (2) When swimmers - in particular under 13 years old - were asked to perform in a longer race, their stroke rate significantly decreased, while stroke length remained unchanged. By contrast, when older swimmers (> 15 years old) performed a longer race, their stroke rate/length ratio was radically different as they were capable of increasing stroke length when stroke rate decreased. The second point is frequently observed in young swimmers and is suggested to be partially related to anthropometric factors. As a swimmer's height and limb size increase during more rapid growth periods, swimmers will be able to perform with a greater stroke length and accompanying lower stroke rate (Mezzaroba et al., 2014), suggesting progress in biomechanical efficiency.

The influence of body composition and lean mass have also been identified in swimming biomechanics, particularly in terms of stroke length and stroke efficiency development. Multiple measures have shown relationships between anthropometric properties (e.g., height; trunk length; arm span; arm, forearm & hand lengths) and propulsive force produced, even when accounting for maturation status (Moura et al. 2014; Costa et al., 2006). By comparison, the relationship between body composition, stroke rate, length, index and propulsive forces are more complex. It seems more relatively clear that body fat percentage, fat-free mass, lean mass and arm muscle area are correlated to propulsive force production, contributing to swim performance. While all parameters mentioned are positively correlated, body fat percentage is negatively correlated. However, there is no evidence suggesting that an increase in muscle mass and lean mass before and during maturation accounts for the observed variations in stroke length, rate and index. It also appears that these parameters also do not necessarily relate to performance improvement (Moura et al, 2014; Mezzaroba et al, 2014). In other words, changes in body composition, due to growth and maturation, do impact stroke length and help improve swimming efficiency. On the other hand, the increase of muscle and lean mass via specific strength and conditioning program may not necessarily, and so obviously, contribute to swimming performance improvement. These findings suggest that 'dry-land' or 'activation' sessions for young swimmers may be more facilitative for developing appropriate movement patterns and developing relative strength & conditioning associated with injury prevention. Overall, performance improvement throughout across maturation stages may be more primarily related to the increase in swimming efficiency. With efficiency improvement partially accountable by anthropometric development, it is also strongly influenced by the adequate development of fundamental swimming skills. These skills are highlighted as the “non-negotiables”, irrespective of individual age, maturation stage or physical capability (i.e., strength, size or mobility). The following now provides details on some of the most important fundamental skills and which are also relevant to ‘the starts’ and ‘the turns’ respectively.

Fundamental biomechanical swimming efficiency

Developing an efficient swimming technique requires (i) an appropriate body posture; (ii) effective and efficient production of propulsive forces; (iii) an appropriate kicking technique; (iv) adequate breathing technique; and (v) a correctly timed body roll.

(i) Body position and posture

For any swimmer a neutral spine position is important. A neutral spine is the natural alignment of one’s vertebrae which may include subtle thoracic and lumbar curves. When correct neutral alignment is achieved, the position will maximise the body’s ability to perform a movement whether it be power, skill or speed. Incorporating a neutral spine is paramount also for streamlined alignment and full extension of the major body segments. The posture also reduces the amount of drag during swimming and changes the centre of mass to achieve a neutral rotation along the body’s frontal axis (i.e. bringing the hips and feet down and shoulders up). The streamlined position in reference to free swimming is defined with aligning the hands and the arms on the water surface, with shoulders fully extended and the elbows close to the head. The hips have to stay high on the water surface and the feet trailing in the shadow of the hips (see Figure 7.1 & 7.2).

Figure 7.1: Body position & posture. Freestyle example (Honda, 2017)

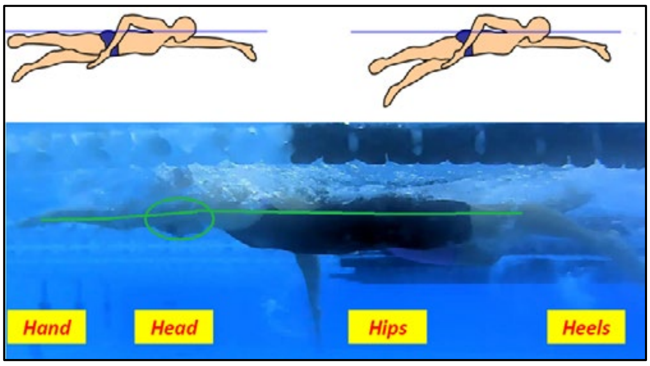
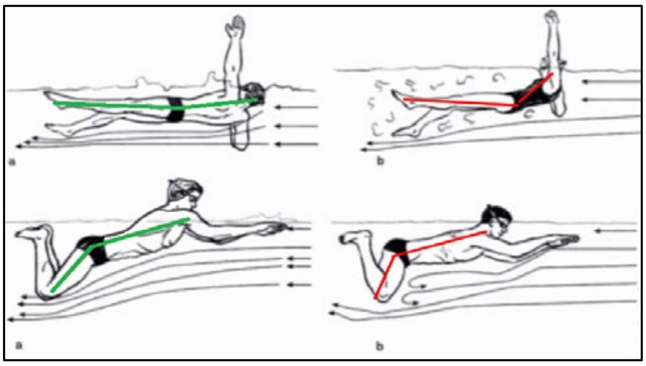


Figure 7.2: Neutral body position & posture. Backstroke & Breaststroke example (adapted from Maglischo, 2003).

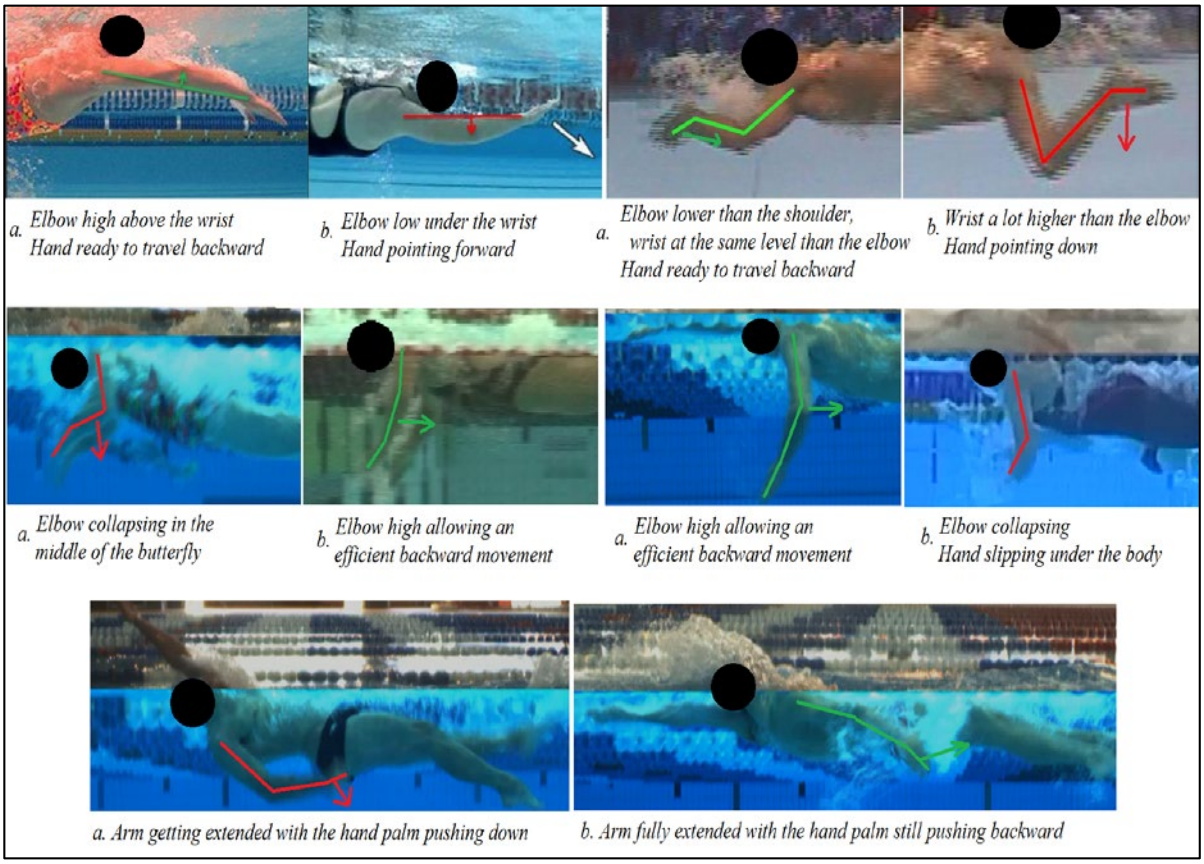


The head position is a key determinant to maintain a good body position and minimise the drag encountered. The swimmer has to place their head in a neutral position with the eye-line to the bottom of the pool, and the arm(s) touching the ears to minimise resistances.

(ii) Stroke characteristics

During a swimmer's growth, and particularly before and during maturation, the work implemented to develop stroke technique should focus on ensuring the application of high propulsive forces. When performing any stroke, arm orientation should aim to push the water in the opposite direction to the intended direction. This includes, for example, a hand entry with full upper-body extension; hand exit beyond the hip line (elbow fully extended); orientation of propulsive surfaces (i.e., hand and forearm) backwards and towards the feet; and, a "high elbow" position allowed by a controlled internal rotation of the shoulder. Also important is a symmetrical stroke. Left and right arms must be coordinated (simultaneously or alternatively) to achieve high force production along with bilateral breathing. Finally, maintaining good body balance is another key element. This means keeping the head in a neutral position, hips high, all limb/segments aligned (core control) and having a smooth, efficient, body roll. Refer to Figure 7.3 for a diagrammatic summary.

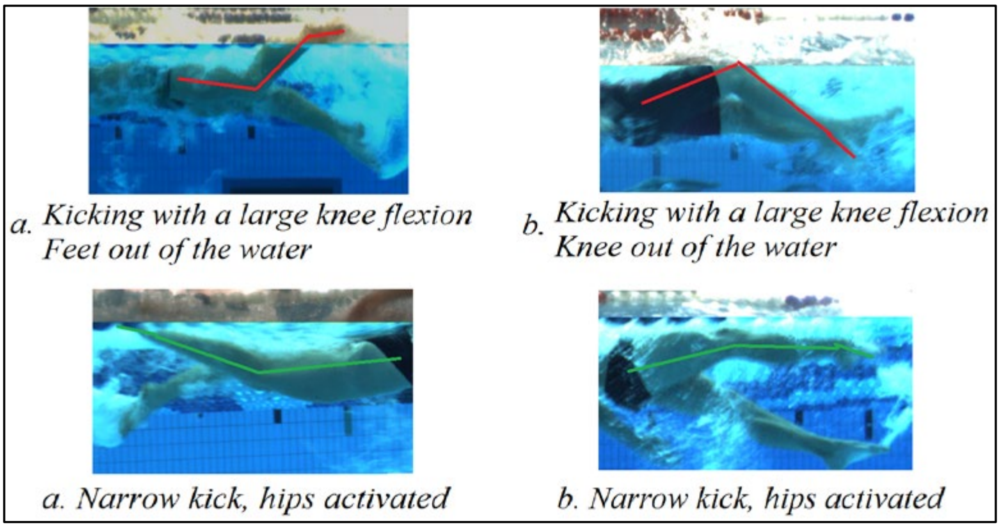
Figure 7.3: Key stroke characteristics to develop propulsion efficiency.



(iii) Kicking technique

A proper kicking technique must be developed at an early age with the aim to provide support to the arm strokes and improve body balance (see Figure 7.4). At that stage, kicking technique shouldn't rely on the leg power or on the knee and ankle flexibility. Any early training on the kicking technique should prioritise the production of small and narrow movements initiated at the hip level, with good activation of the gluteal muscles and the feet always in the water (rather than kicking with the knees, activating the quadriceps and with the feet out of the water at the end of every kick) (see Figure 7.4). During early development, kick technique should avoid generating leg power from the knees and over-emphasising ankle flexibility.

Figure 7.4: Kicking technique to help develop propulsion efficiency.



(iv) Breathing

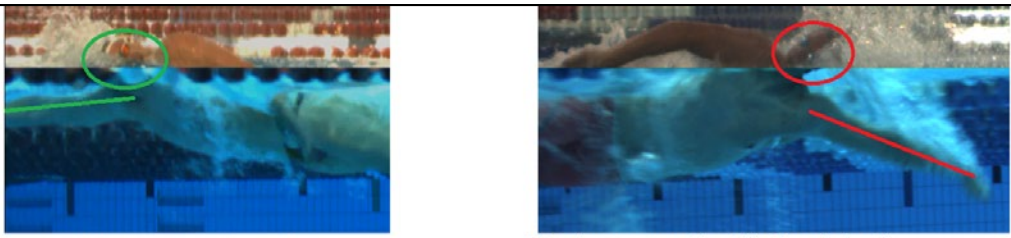
Breathing technique is an often forgotten - though important component - in swimmer's efficiency and body balance. During growth, it is recommended swimmers develop bi-lateral breathing within freestyle swimming in which the head movement is controlled. With every stroke, the head should stay in a neutral position as much as possible when breathing. This implies that the chin stays quite low when taking a breath in butterfly and breaststroke. In freestyle, any vertical movement should be removed and the head rotation limited to 90º maximum. When reaching maturation, swimmers should be capable of taking a short breath (i.e., quick rotation of the head) without collapsing the supporting arm (see Figure 7.5).

(v) Body roll and timing

The body roll (rotation) and its timing are critical in swimming and have influences upon the overall body position, stroke efficiency, kicking technique and breathing. Multiple timing and body roll

However, it is important to develop appropriate body roll at an early age. The initially developed body roll should help maintain neutral body alignment, help the swimmer engage the elbow during all strokes as well as not expose the shoulder to unnecessary pressure and allow a 'clean-hand' exit.

Figure 7.5: Breathing technique to help develop propulsion efficiency.



a. Head rotation: 90 (1goggle in, 1 goggle out)
Front arm steady on the water surface, close to the head
Hip and core controlled

b. Head over-rotated and looking behind
Front arm collapsing increasing the drag encountered
Left hip falling down

Fundamental biomechanics of 'starts', 'turns' and 'underwater kicks'

Observations of swim performances at International championships over the past 20 years demonstrates the continuously growing importance of the non-free swim parts of the race (i.e. the start, turns and underwater kick sections). Therefore, the biomechanical and learning of such skills is likewise important to the developing swimmer.

'Starts'

The start includes all actions executed on the block, during the aerial phase, at the point of water entry and underwater through to 'the breakout'. The production of a high horizontal velocity at 'take-off' and water entry is known to be the most important factor to reach a good level of performance during the start. Whilst the force and power produced on the block are two critical parameters to maximise this horizontal velocity (Tor et al., 2015), they do not appear to be key elements to focus on before reaching full neurological and physical maturity. Prior to maturity, it seems more appropriate to develop the biomechanical technical qualities that underpin an effective dive movement (see Figure 7.6 & 7.7). These qualities include a good awareness of the role and action all limbs and muscles on the block, knowledge of a good aerial trajectory, and the ability to attain a biomechanically strong, streamlined, position at water entry and during the glide.

Figure 7.6: Key biomechanical actions in the forward dive start.

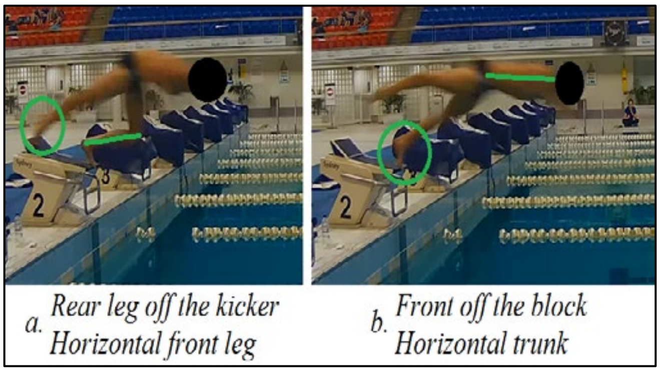
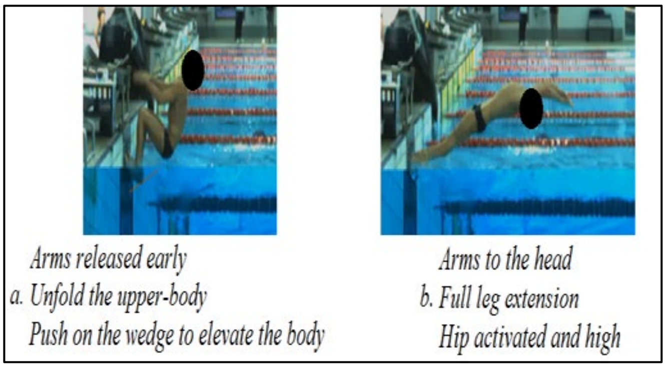
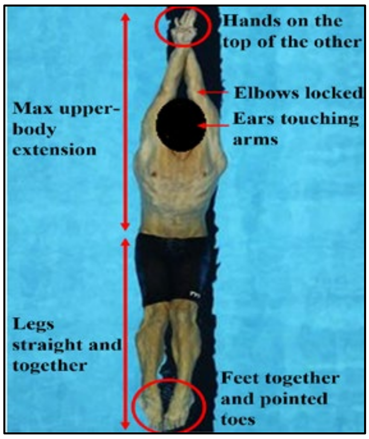


Figure 7.7: Key biomechanical actions in the backward dive start.



Generally speaking, similar movement principles also apply for the backstroke start. Here swimmer's should aim to: (i) quickly push on the handle-bars and throw the arms to the head and unfold the upper body; (ii) produce a fast and maximal contraction of the quadriceps until reaching full leg extension, elevating the body up and producing body velocity; and (iii) producing maximal gluteus and hip muscle activations to permit maximal body extended aerial trajectory (see Figure 7.7). Once leaving the block or wall (aerial phase), the swimmer should maximise flight distance, reaching full body extension and ensuring a strong streamlined water entry. A biomechanically appropriate water entry is also important to guarantee a transfer of velocity from the aerial to underwater phases of the start. This too is a technical element to be mastered. Finally, attention should be given to the capacity to hold an efficient streamlined position from water entry through to breakout, as shown in Figure 7.8.

Figure 7.8: Biomechanical streamline position for glide efficiency (adapted from pinterest.com)



The streamline position is a reference position in swimming to help maintain velocity and reduce drag. It should be perfectly mastered as early as possible and the value of holding this glide position after a dive or a turn should be understood at a young age.

‘Turns’

Every turn can be described as comprising three parts: The approach, the roll/rotation (including the actions on the wall) and the underwater phase (glide and underwater kick). A good approach to ‘the turn’ requires managing the distance to the wall (good perception and robust cues), keeping a high velocity during the last couple of strokes and using the last stroke to initiate the turn. Developing a good rotation/roll may be challenging for young swimmers as such a skill requires complex rotational movement at a fast speed and with precision. The complexity of the turn invites breaking down the movement into smaller, easier segments, and then slowly adding complexity when competency is demonstrated. In every case, the biomechanical priorities in performing an efficient turn, regardless of developmental stage should be:

1) Bring the knees close to the chest (tuck position) as quickly as possible to facilitate rotational speed in the turn.
2) Place the feet on the wall parallel to each other, at the same level (not staggered) and hip-width apart.
3) Having feet contacting the wall at the same time (not adjusting the feet with small steps on the wall) and simultaneous parallel wall contact with hands for touch turns.
4) Extending the arms around the head with the elbows and hands locked together as soon as the legs start pushing on the wall.

Other elements such as the reduction of contact time and the level of force or power produced on the wall is not a primary focus and may be trained later in the swimmer’s development. Finally, swimmers should adopt the same streamlined position as for ‘starts’ (see Figure 7.8) and be able to hold the gliding position before initiating underwater kicks. At an early stage of maturation, identifying the optimal time to begin underwater kicks is not a priority as long as the swimmer understands the importance of holding the glide and developing proprioceptive skills to improve the perception of their water speed.

‘Underwater kick’

Travelling underwater using dolphin kicks is extremely challenging for young swimmers as it requires an advanced level of physical and physiological development (i.e., hypoxia management, core and lower leg strength etc.). Underwater kicking technique requires performing high-intensity movements for a relatively long duration and with a limited quantity of oxygen. Swimmers at an early stage of maturation will consequently have to work safely on their breathing control while remaining under water. Whilst it is difficult to attain high underwater kicking velocities at an early stage of maturation, swimmers should still focus on developing an accurate movement pattern. The underwater kick is characterised by: (1) A rigid, stiff and fully extended upper-body. The hands, arms, shoulders and head must stay steady and in a streamlined position. (2) A narrow and fast dolphin kick (rather than a large & heavy kick). (3) Even downbeats and upbeats in a rhythmical pattern. (4) Actively controlled joints (not pushed by the water), particularly during the transition from the upbeat to the downbeat. It is important for young swimmers to focus on developing dynamic, fast and well-controlled transitions between every phase of the starts and turns.

8. Growth & maturation in swimming: A summary of recommendations

(Mark Osborne & Stephen Cobley)

Swimming is a sport with complex performance demands, including technical, biomechanical, physiological, anthropometric and psychological facets. The complexity is also compounded by the fact that there are substantial variability and dynamic change in these various facets over time; all of which are observable when tracking swimmers who are competing from an early age. As such, coaches need to have knowledge across many areas; adopting a multi-disciplinary approach to their coaching instruction and practice with developing swimmers. As highlighted in this resource, many factors need to be systemically considered and synthesised overtime to help each swimmer reach their potential. Growth and maturation, and its potential variable trajectories between individuals during youth ages is one key factor affecting swimmer development. Growth and maturation are considered important as it affects many of the facets comprising swimming performance.

Knowledge and understanding of maturation and its potential impact on various facets of swimming necessitates careful consideration. The content of this resource has documented how maturation status directly influences swimming performance (see e.g., Figure 1.5 & 1.6). Further, how growth and maturation impacts various aspects of physiological development (i.e., aerobic & anaerobic development); can associate with injury; affects neural/muscular coordination and skill-acquisition; can affect biomechanical and technical aspects of swimming performance; and, has potentially significant implications for strength & conditioning; nutritional intake, as well as training/competition load scheduling (to list but a few key points) has all been highlighted. Based on the preceding sub-sectional content, this final section now summarises key 'action recommendations' derived from key implications highlighted within and across respective sub-sections. The action recommendations are identified with a view to addressing two aims: (i) help Swimming Australia members, in particular practitioners (i.e., coaches) identify strategies to mitigate against the possible less preferable outcomes associated with growth and maturation; and (ii) help Swimming Australia members identify strategies that promote longer-term inclusive participation and performance development beyond maturation and into adulthood.

Action Recommendation 1. At a minimum, coaches and parents should periodically measure and identify the developmental differences of their swimmers. Specifically, the growth and maturation status for girls aged 9.5-16.0 years and boys at 11.5-16+ years. At the same time, the relative age status of swimmers (i.e., relatively older or younger) within annual-age group events should also be identified. Such measurement and identification would help determine individual and group maturational and relative age status differences; the time-points away from peak-growth; and, help identify forthcoming expected growth changes. Measurement will also help coaches, parents and swimmers better understand the potential sources of inter-individual development and performance variability; outcomes not immediately apparent when undertaking typical age-group comparisons. Measurement can also inform swimmer selection and evaluation by determining whether performance is being (dis-)advantaged by maturity or relative age status within age-group events.

Aligned with recommendation 1, coaches/parents should measure maturity status regularly (e.g., 3-4 x year), with more frequent measures during growth spurts or around peak-height velocity. Likewise, determining relative age within specific competition age-group events is valuable as the dates used for age-grouping are often changeable between swimming events. More specific to maturation, as growth timing and rates are variable between and within individuals, it is recommended that periodic measurement be conducted to keep an updated understanding of maturation status. During time-points around peak-height velocity, greater frequency is required as growth rates can change substantially within short-time periods (i.e., days/weeks). Accelerated growth in short-time frames (i.e., high tempo) is accompanied by numerous bodily changes (e.g., hormonal, neural, tendon, muscular etc), leading to time-periods of movement instability, coordination loss and injury vulnerability. Minimising the occurrence of such detrimental outcomes is important to long-term swimmer development; thus justifying more rigorous monitoring and management.

Coaches, along with parents/swimmers, should aim to track maturity status and performance development together longitudinally over time. Such tracking will help coaches observe the potentially variable trajectories of swimmers over time (i.e., across age groups); help understand individuality in performance development patterns; help better understand and compare responses to training programs; and, help more accurately evaluate swimmers given their maturational and relative age stages of development. Graphically plotting performance development over time according to developmental status for individuals (and across swimmers) in respective strokes is at the core of Action Recommendation 1. Further information on how to determine maturation status, relative age and how to measure these developmental features will be provided by Project H2gr0w in due course.

Action Recommendation 2. Coaches should monitor training and competition loads alongside injury occurrence during ages associated with growth and maturation. During the junior and adolescent years, the opportunities to participate and compete in multiple, frequent swimming events within a competitive season are numerous. Likewise, there is potential to be involved in highly intensive training loads (i.e., high volume, duration, intensity & frequency) within local swimming programmes. Further, there is the potential to be training and competing at various representative levels (school/club etc.) without complete knowledge and awareness of total training and competition loading. While beneficial to skill and performance development, high ‘unregulated’ training and competition loads can increase the risk of fatigue/exhaustion, overtraining (i.e., psychological & physiological well-being decrements) and injury. As such, during growth periods - particularly around maturation - it is particularly valuable as a coach/parent to monitor loading, including training/competition loads being accumulated across different tiers or participation/representation. Monitoring and regulating training/competition may also be socially challenging, as performance increments may occur at this time. It is important to consider, however, whether performance improvements are more related to growth and maturation processes as opposed to training and coaching programmes *per se*. Rather, around peak-growth, consideration of actually avoiding acute and chronic excessive training load exposures beyond pre-existing levels, or reducing training/competition, loads will be beneficial. Preserving psychological and/or physiological well-being and avoiding typical injuries associated with the maturational process is beneficial here in the short-term and longer-term.

As a component part of monitoring training and competition loads, coaches/parents should monitor the fatigue, psychological-well-being, sleep disturbance and signs of relative energy deficiency during growth and maturation periods. To observe the physiological and psychological responses to intensive swimming engagement, it is worthy to monitor morning resting heart rate, evaluate sleep patterns, mood, perceived wellness, appetite, muscle soreness and fatigue. Together, these will provide a brief but informative insight toward how well a developing swimmer is responding to a prescribed training load, alongside any other additional stressors presently coexisting in their lives. Additional stressors may relate to external sources, such as school progress, social relationships and/or family circumstances for example. Importantly, understanding how an athlete is adapting to forms of stress (training or social), provides insight for coach in prescribing training and helping protect against the occurrence of detrimental outcomes. Coaches should also be tracking when a swimmer is required to modify training, regularly reviewing patterns of behaviour and relationships with prescribed training loads. Failure to track wellness and the responses to training effectively means the coach may be oblivious to a range of factors that may affect training responses and performance at a time of instability and change.

Action Recommendation 3. Coaches should screen for shoulder, knee as well as core strength and flexibility. Coaches should consider training load tempering in accordance with strength and flexibility, particularly around peak-growth periods to reduce injury risk. It is important for coaches and swimmers to track strength and flexibility on a regular basis, along with any associated pain or soreness. Changes in one - or all - of these parameters may confirm structural changes associated with growth and maturation, or potential injury (training load) related issues. It is recommended that swimmers learn to record and report these parameters, helping identify associations between training load and soreness. Joint or muscle soreness may be associated with total swimming volume, may associate with training/competition in a specific stroke, or may associate with swimming at a given level of intensity or work rate. Irrespective, such information needs to be reported and shared between coaches, parents and any medical support staff to optimise management/treatment. Coaches can then modify training and competition load if necessary, to minimise any further soreness or pain and reduce the risk of further injury. Coaches and parents should ensure athletes seek a diagnosis upon an athlete presenting with any signs or symptoms of soreness over and above training-induced fatigue. Athletes should ensure they communicate with both, or either, the doctor or physiotherapist their training history and observations. Any diagnosis or recommended treatment plans from any medical staff should be communicated and shared with the coach.

Action Recommendation 4. Implementation of 'lighter body-mass load' dry-land strength and conditioning should generally occur pre and during peak growth. At these maturational stages, swimmers should have an injury prevention focus in their dry-land exercise program. These programs should emphasise exercises that complement and contrast the work undertaken in the pool, ensuring muscle imbalances do not occur, which subsequently can lead to injury. At this athlete developmental stage, swimmers should ensure each exercise is performed with 'correct or adequate technique' and not - by contrast - to the point of fatigue or failure due to excessive resistance loads. Prior to and during any observed rapid increases in growth, coaches should focus only on technical development of swimmers. For example, learning how to lift properly and safely. Coaches should incorporate the basic exercises and movement patterns that form the building blocks of more complex lifts that will most likely be required later in their athletic development.

Coaches should only target 'higher-load' progressive strength & conditioning (e.g., resistance training) post-peak height growth in 'dry-land' and 'in-water' contexts. Beyond the period of PHV, swimmers can begin to move through the exercise options to select more complex movement patterns in their dry-land training. Only with sound fundamental movement pattern techniques, should coaches consider increase dry-land loads and exercise complexity. The same applied to 'in-water' training, where coaches may introduce training aids such as hand paddles and drag devices to increase resistance and load. Whilst athletes may begin with single joint/single plane and basic multi-planar movement patterns in much of their dry-land training, only when the athlete has a solid strength foundation and where there is no sign of strength deficiencies or muscular asymmetries, can the training program incorporate more complex multi-joint, multi-planar movement patterns (e.g., Olympic style lifting or plyometric training). This is where more challenging concepts such as eccentric training to stimulate muscle and strength development can be introduced where appropriate. Such training methods should only be introduced under the supervision of an experienced strength & conditioning provider, and with load monitoring occurring as part of the broader process of swimmer development.

Action Recommendation 5. Coaches should ensure educational nutritional resources are available for parents/swimmers involved in intensive training/competition coinciding with growth and maturation periods. As explained in sub-section 5 of this resource, there is a legitimate energy cost to growth and maturation in addition to that required for swimming training and competition. Compared to senior-elite swimmers, younger swimmers are still undergoing physiological growth, are often less technically proficient and yet are often exposed to 'higher-level' (high volume and intense) training programs for the first time. They, therefore, require more fuel for a given amount of work in the pool. It is therefore important that all those associated understand the energy requirements of prescribed training loads and consider periodised energy intakes, akin to periodised training. As training requirements change across the weekly training cycle/s, accordingly the amount (volume) and content of food may need to change, particularly as athletes enter a taper phase where training volume decreases and where physiological recovery before competition is required. Coaches are thereby encouraged to engage with sports dietitians and recommended to collate appropriate resources to educate parents and young swimmers about appropriate nutrition planning and energetic requirements.

Action Recommendation 6. Coaches should encourage wide-ranging exploratory skill/technique development, along with stroke and activity sampling at pre and during maturation stages. Coaches should establish wide-ranging, variable but controllable movement patterns in swimming technique.

Only beyond the peak height velocity period should more specialised stroke-specific training be implemented. An expanding collection of literature examining athlete development across multiple sports identifies cross-transfer benefits from learning and engaging in a variety of sports contexts. Even within a sport such as swimming, sampling different strokes and movement activities is predicted to reap neurological, coordination and movement control benefits alongside physiological development. Further, during maturation, being regularly exposed to trialling an array of movement techniques with problem-solving approaches in coaching and instruction is perceived to add to the development of a broad movement repertoire under volitional control of the swimmer. During peak-growth and as the body undergoes structural change, constant re-calibration of neural and muscular movement with feedback from the sensory systems is required. Being able to control, adjust and adapt movement throughout anatomical and physiological change is likely important to continued movement stability and performance development without injury from unstable, un-intentional movement. The avoidance of muscular and flexibility imbalances across and within joint areas from consistent, repetitive training is also important to avoid injuries at this stage. Only when the rapidity of anatomical and physiological change has slowed (post-maturation), and because of 'rounded' muscular (physical) development, is the deployment and rehearsal of consistent, specialised and stroke-specific movement patterns recommended with transition into adult competition.

Action Recommendation 7. Coaches should focus on learning (or re-establishing) 'fundamental biomechanical technique' across all stages of growth and maturation status. Anatomical and physiological changes during growth and maturation necessitate periodic checks to re-affirm fundamental biomechanical principles in stroke efficiency. Coaches should maintain a visual record (e.g., notes, diagrams, video) of a swimmers technique on a regular basis to ensure technique is not changing (or is actually changing) if that is the intended purpose of the training intervention. As part of the coaching process, coaches should ensure swimmers undertake a regular or periodic series of skill drills to reinforce fundamental swimming technique. A visual record of technique in key training drills or standardised tests with controlled exertion (e.g., controlled stroke rates and/or 100% race pace) should be stored as a reference. As swimmers then progress through the various growth and maturation phases, coaches can then reassess and compare swimming technique. By having previous footage as a reference, coaches can then identify aspects of stroke technique which have changed as body dimensions have changed, or technical aspects not being maintained during heightened testing (e.g., increased stroke rates; fatigue etc). By having reference visual records of biomechanical positioning and skills, coaches may also be able to isolate and address any fundamental concerns during training. As athletes progress through the maturation phase, they may be able to develop new technical proficiencies which can then be benchmarked for future reference. Such referencing of biomechanical and technical proficiency within strokes may also inform the likelihood of future injury and other accompanying physiological changes.

Action Recommendation 8. During ages associated with maturation variability, coaches should evaluate individual performance relative to others, only when maturation status and relative age is considered or factored into the evaluation process. A perennial problem within competitive youth swimming is that within typical age-group swimming events, swimming performance, evaluation and selection consistently favours the earlier maturing and relatively older swimmers for both boys and girls, up until maturation has ceased. As a result, 'later maturers' and those who are 'relatively younger' within similar age-groups are consistently disadvantaged, due to substantial differences in physiological and anthropometric characteristics between their age-group peers. The consequence is that there is substantially far fewer later maturing and relatively younger swimmers participating and competing in swimming at an early age. Yet following maturation, this number by proportion substantially increases with predicted longer-term benefits.

To avoid such 'maturity' and 'relative-age' biases, evaluation has to consider maturation status and relative age-associated variability between swimmers. There are several strategies that can be used to more equitably evaluate and compare swimmers. For example, by putting into action recommendation 1 (see above), would lead to coaches having maturity and relative age swim performance information on individuals and training groups over time. Graphically plotting such data would identify performance change according to maturation status, for example, enabling comparisons of individuals at given maturity points. With more substantial data from across training groups or cohorts, individual swimmer progress can be better evaluated. Adjustments to performance times based on maturity differences can also be calculated and used to help remove maturity- or relative-age associated-biases. Further information related to performance adjustments will be made available from Project H_2gr0w in the near future.

An executive summary of the action recommendations discussed is now provided below in Table 8.1.

Table 8.1: A summary of key action recommendations based on resource content.

No:	Action Recommendations
1.	(a) Coaches/parents should measure growth and maturation status in swimmers (girls: 9.5-16.0 years; boys: 11.5-16+ years). (b) Coaches/parents should measure maturity status regularly (e.g., x3-4/year), with more frequency during growth spurts or around peak-height velocity. (c) Coaches/parent/swimmers should track maturity status and performance development together longitudinally over time.
2.	(a) Coaches should monitor training and competition loads as well as injury occurrence during ages associated with growth and maturation. (b) Coaches/parents should monitor fatigue, psychological-well-being, sleep disturbance appetite and signs of relative energy deficiency during growth and maturation periods.
3.	(a) Coaches should screen for shoulder, knee and core strength as well as flexibility. (b) Coaches should consider training load tempering in accordance with strength and flexibility screening, particularly around peak-growth periods to reduce injury risk.
4.	(a) Coaches should generally implement ‘lighter’ body mass-load dry-land strength and conditioning activities pre and during peak growth. The emphasis of dry-land training at this stage should be on technical skill development and injury prevention. (b) Coaches should target ‘higher-load’ progressive strength and conditioning (e.g., resistance training), post-peak height growth in ‘dry-land’ and ‘in-water’ contexts. Emphasis is on strength development with solid technical skill grounding (e.g., dry-land complex lifting in resistance training).
5.	Coaches should seek to ensure educational nutritional resources are available to parents/swimmers involved in intensive training/competition coinciding with growth and maturation periods.
6.	(a) Coaches should, during pre and during maturation stages, encourage wide-ranging exploratory skill/technique development along with stroke and activity sampling. Coaches should establish wide-ranging, variable but controllable, movement patterns in swimming technique. (b) Coaches should, only post-peak height velocity, consider more specialised stroke-specific training working toward more specific techniques for competitive performance.
7.	Coaches should focus on learning or re-affirming ‘fundamental biomechanical technique’ across all stages of maturation status. Anatomical and physiological changes due to growth and maturation necessitate periodic checks to (re)-affirm fundamental biomechanical principles in stroke efficiency.
8.	Coaches should, during ages associated with maturation variability, only evaluate individual performance relative to others when maturation and relative age status is considered or factored into the evaluation process.

Summary:

This educational resource was explicitly written with the aim to assist Swimming Australia coaches, parents and young swimmers. Resource content has firstly summarised and explained the growth and maturation process, highlighting its importance to performance and longer-term development. Second, the resource has summarised and explained how growth and maturation impact various facets of swimming, highlighting key concerns or potentially detrimental outcomes. Thirdly, across sub-sections, resource content has also highlighted key implications, including consideration of strategies to mitigate the occurrence of less preferable outcomes (e.g., performance (dis-)advantages; injury and fatigue during circa peak growth). Finally, key action recommendations have been established based on the collated information presented. Recommendations have been listed as action recommendations; an achievable list of ‘to do’s’ that Swimming Australia members can implement with a view to promoting ‘better coaching practices’; whilst keeping a longer-term aim of promoting inclusive participation and performance development beyond maturational ages and stages. Collectively, it is predicted that by implementing such action recommendations more support for young developing swimmers will occur, helping them make a successful transition from youth to adult swimming.

If coaches, parents or swimmers would like to seek further information or have specific questions related to the information contained within this resource, you are advised to contact either Project H_2gr0w or Swimming Australia directly using the contact details provided below.

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Steve is an Associate Professor in the Faculty of Medicine & Health at The University of Sydney. His research interests examines factors that facilitate or inhibit athlete development from a multi-disciplinary perspective. His research and applied work has led to the evaluation, modification and writing of athlete development programs and policy for numerous sport organisations. Steve is the joint project leader for Swimming Australia's 'Project H2gr0w' initiative. Steve has also previously co-edited "*Talent identification and development: International perspectives*" (Routledge, 2012) and "*The Routledge handbook of talent identification and development in sport*" (Routledge, 2017).

James Salter

James is General Manager of the Performance Pathway at Swimming Australia. James has over 15 years of experience in athlete and coach development across numerous sports. His role at Swimming Australia specialises in driving change among coaches, performance support staff and athletes in a multi-disciplinary manner and creating athlete profiles that influence the preparation of future Olympians. He served as the Performance Operations Manager at the English Institute of Sport from 2005-2013 and is a former Olympic finalist, World, Commonwealth and European swimming medallist.

Jacco Verhaeren

Jacco is the National Head Coach for Swimming Australia with more than 25 years' experience coaching athletes to multiple international honours over six Olympic cycles. He is best known for guiding Pieter van den Hoogenband, Inge de Bruijn and Ranomi Kromowidjojo to multiple Olympic gold medals. He was formerly the sporting director of the Dutch swimming team and the Nationaal Zweminstituut Eindhoven.

Shaun Abbott

Shaun is presently a PhD candidate in Exercise & Sport Science in the Faculty of Medicine at The University of Sydney. In collaboration with Swimming Australia, Shaun is investigating key issues in athlete development, specifically the influence of growth and maturation during adolescence upon talent identification and development. Shaun is a leading project member of the 'Project H2gr0w' initiative. Shaun is also a former swimmer.

Sally Clark

Sally is the lead physiologist for Swimming Australia. Sally has been in this role for 12 months. Prior to working for Swimming Australia, Sally was a member of the Department of Physiology at the AIS for 21 years. During this time she worked with many sports including Water Polo, Triathlon, Race Walking, Rowing, Basketball and Tennis. Her research interests include altitude training, muscle metabolism and the female athlete.

Peter Fricker

Dr. Fricker is Chief Medical Officer to Swimming Australia, and is a sports physician with over 45 years of experience in sports medicine practice, research, teaching and administration. He served as the Director of the

Australian Institute of Sport from 2005-2011, and has attended five Olympic Games and six Commonwealth Games as a team physician and Medical Director. He is Chair of the Medical Commission of the Australian Olympic Committee, and is member of the Medical Commission of the Oceania National Organisation of Olympic Committees (ONOC). He has edited and authored three text books and numerous research publications.

Ivan Hooper

Ivan is a Sports Physiotherapist with nearly 30 years of experience in elite sport. He is currently Lead Physiotherapist for Swimming Australia. He works in private practice at Queensland Sports Medicine Centre, and consults to the Queensland Academy of Sport & Archery Australia. He previously held the role of Sports Science/Sports Medicine Coordinator with Rowing Australia where he was team physiotherapist for 16 years. Across kayaking, rowing, diving and archery he has attended five Olympic Games as team physiotherapist. He has had a long term interest in adolescent sport and long term athlete development.

Scott Dickinson

Scott is the National Lead for Strength & Conditioning (S&C) for Swimming Australia. He possesses a Masters in Strength & Conditioning from Edith Cowan University. Scott has extensive experience in athletic development having coached both talent and elite level athletes across a number of Olympic and Professional sports over the past twenty years. He was previously the National Lead for S&C for The Netherlands Olympic Committee between 2009-2016 where, in addition to coordinating the delivery of programs to the various programs, he also led and coordinated the S&C program for the Dutch national swimming program.

Greg Shaw

Greg is the nutrition lead for Swimming Australia. He was a senior sport dietitian at the AIS for 10 years and has worked with the Australian Swim team since 2004. He has extensively researched nutrition for swimming focusing on supplementation, energy intake, energy expenditure, buffering capacity, and more recently the use of dietary collagen protein intake to aid in the repair and regeneration of connective tissue. He is also a level 3 anthropometrist who has written and been involved in numerous projects targeted at improving the collection and interpretation of body composition data.

Damian Farrow

Damian is Professor of Skill Acquisition within Victoria University's Institute for Health and Sport. From 2002-2019, Damian was also the senior Skill Acquisition Specialist with the Australian Institute of Sport. As part of this role he worked as an advisor to Swimming Australia assisting coaches to enhance the design of swimming practice. His research interests examine the factors that influence the development of sport expertise with a focus on skill practice design methodology. He has published and presented to scientific and coaching audiences extensively on these topics over the last 20 years.

Marc Elipot

Marc has a Ph.D in Biomechanics and Motor Control applied to high performance in swimming. He has been working in the high performance industry for the last 15 years with numerous sports and is currently Swimming Australia's national lead for Biomechanics, based at the Australian Institute of

Sport. His main role is to develop and lead world-leading biomechanics support, focused on improving athletes' performances. Marc's main research interests include understanding the optimal swimming technique, and more particularly the development of the specific synergies and coordination supporting it.

Gina Sacilotto

Gina has a Ph.D. in hydrodynamic forces in swimming, reflecting a combined project between the Australian Institute of Sport and the University of Canberra. Gina has been working in various capacities in the high-performance swimming industry for the last ten-years and is currently the Sport Science Coordinator for the Carlile Swim Team based in NSW. Gina's main roles are to develop and assist with performance support across all competitive squad programs, create education workshop from other disciplines such as nutrition and psychology as well as progress research and innovation in applied swimming projects.

Cecilia Nguyen

Cecilia has worked within high-performance swimming for the last 8 years in a variety of roles, including as a biomechanist and pathway program manager. Cecilia has an honours degree in swimming biomechanics and is now combining her expertise in sports science and athlete pathway development to deliver a comprehensive pathway program for Swimming New South Wales.

Mark Osborne

Mark is one of Australia's Senior Sports Scientists with almost 20 years experience at the Queensland Academy of Sport prior to joining Swimming Australia in 2013. Mark has worked extensively with elite athletes across multiple sports, attending numerous World Championships/Olympic Games to provide scientific support. At Swimming Australia, he has overseen the expansion and development of Sport Science and Sports Medicine networks in line with development of the High-Performance Centre network. He has initiated several innovations and has continued to change the culture of service to ensure best practice for coach and athlete support.

Referencing:

To reference this resource generically, please reference using the details below. The below examples are set out in APA format.

Cobley, S., & Salter, J. (2019). *Project H_2grOw - The impact of growth & maturation on athlete development in swimming: Considerations for coaches, parents & swimmers*. Brisbane, Australia: Swimming Australia.

To reference a particular sub-section of this resource, please reference using the following guideline which illustrates how to reference sub-section 8:

Osborne, M., & Cobley, S. (2019). Growth & maturation in swimming: A summary of recommendations. In Cobley, S. & Salter, J. (Eds) *Project H_2grOw - The impact of growth & maturation on athlete development in swimming: Considerations for coaches, parents & swimmers*. (pp. 52-58). Brisbane, Australia: Swimming Australia.

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