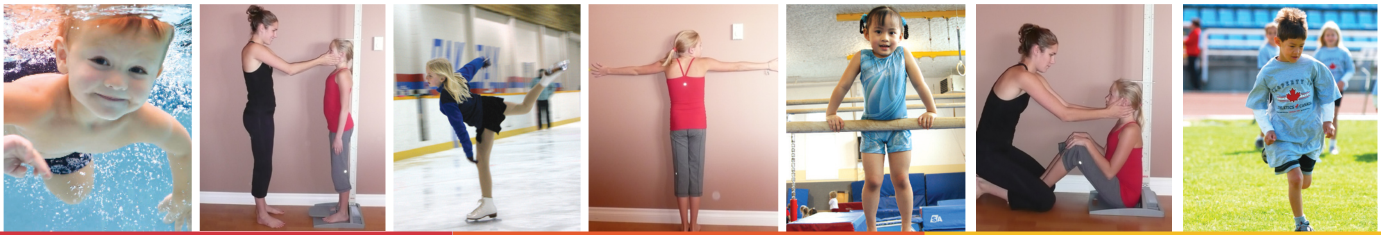

The Role of Monitoring Growth in Long-Term Athlete Development

Istvan Balyi & Richard Way

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Foreward

The following document is intended for coaches who have a solid working knowledge of periodizing annual programs. We hope that the information provided in this document will help coaches develop and deliver training, competition and recovery programs that are specific to the developmental level of the individual(s) they are coaching.

Measurement of Size, Proportion and Maturation

Kinathropometry is an application of measurement to appraise human size, proportion, and maturation; "It puts the individual athlete into objective focus and provides clear appraisal of his or her structural status at any given time, or more importantly, provides for quantification of differential growth and training influences" (Ross & Marfell-Jones, 1991). To identify a young athlete as how typical he/she is for his/her age, a comparison must be made with a representative sample of sex and range. Longitudinal growth velocity curves (see Figure 12) need to be constructed to monitor the growth patterns of athletes to identify their maturity status.

Although growth and development is a natural process, the tempo of the maturation process can vary greatly: "A child with a chronological age of 12 years may possess a biological age of between 9 and 15 years" (Borms, 1986). The difference between a 9-year-old and a 15-year-old is huge; notwithstanding, these athletes are often trained the same way and participate in age group competitions, which give early maturers, especially males, a huge advantage in performance and in the selection process. **For these reasons, the developmental age of athletes should be identified and monitored by coaches.**

Identifying early and late maturers can be done by measurements which track the athlete's growth. Whether one is an early or late maturer is not of issue; the issue is the potential short-term and long-term treatment of such athletes. Appropriate training and competition schedules can be set up for the individual needs of the early, average and late maturing athlete (see Figure 2).

Advanced Knowledge - Age

When a coach considers a training, competition and recovery program for an athlete, the age of the athlete must be considered. This is not done by simply checking the date of birth (chronological age). There are a number of ages which must be considered, including:

1. Chronological age
2. Developmental age (physical, mental and emotional)
3. Skeletal age
4. General training age
5. Sport-specific training age
6. Relative age

Chronological age refers to the number of years and days elapsed since birth. Children of the same chronological age can differ by several years in their level of biological maturation.

Developmental age refers to the degree of physical, mental, cognitive, and emotional maturity. Physical developmental age can be determined by skeletal maturity or bone age after which mental, cognitive, and emotional maturity is incorporated.

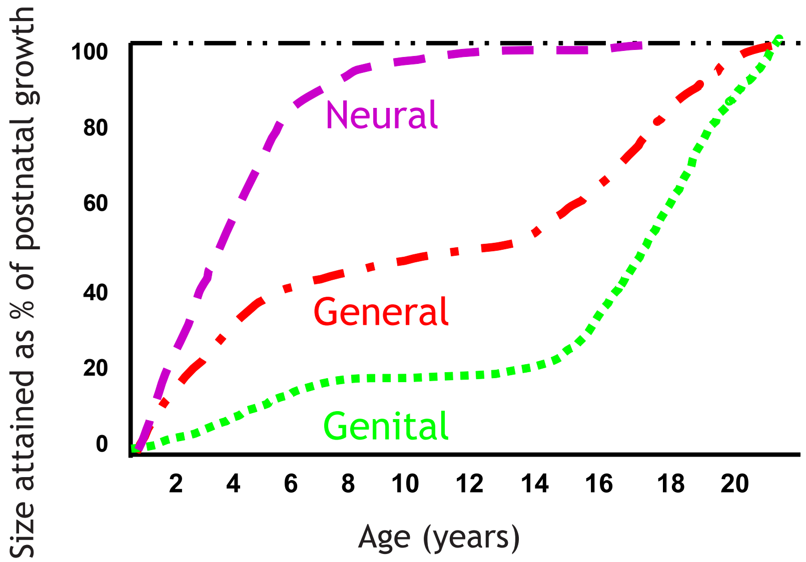
Skeletal age refers to the maturity of the skeleton determined by the degree of ossification of the bone structure. It is a measure of age that takes into consideration how far given bones have progressed toward maturity, not in size, but with respect to shape and position to one another.

General training age refers to the number of years in training, sampling different sports.

Sport-specific training age refers to the number of years since an athlete decided to specialize in one particular sport.

Relative age refers to differences in age among children born in the same calendar year (Barnsley & Thompson, 1985).

Figure 1. Different patterns of system growth during childhood (Adapted from Scammon, 1930)



General curve – This describes the growth of the body in terms of stature and weight. It includes the growth patterns of different systems of the body, such as muscle mass, the skeleton, lungs and the heart. The shape of the curve indicates slow but steady development of the body structure/stature between the ages of five and 10–12 years. In simple terms, this gives the opportunity for skill development at this time. During and after puberty, fitness can be exploited because of maturation of the skeletal structures, muscle mass, lungs, the cardiovascular system and hormonal predisposition.

Neural curve – This describes the growth of the brain and the nervous system. Of the central nervous system, 95% is developed by about seven years of age. The shape of the curve suggests early development of the nervous system will give children the opportunity to develop the movement skills of agility, balance, coordination and speed at the general training age. Fundamental movement and fundamental sports skills can, and should, be developed during childhood.

Genital curve – This shows the patterns of growth of both the primary and secondary sex characteristics. Genital tissue shows slow growth, with a latent period during childhood, before extremely rapid growth and maturation during the adolescent growth spurt. The shape of this curve indicates hormonal maturation, which will have a significant contribution to fitness development and performance improvement.

Why are Growth Measurements Needed?

Growth measurements are needed to monitor and identify the maturity level of the athletes, so training, competition and recovery programs will be designed on developmental age and not on chronological age.

Developmental Age

Figure 2 on the next page illustrates the inequalities of the age group training and competitive systems.

The advantages and disadvantages of being an early or late maturer are described in the advanced knowledge box below with further references to relative age. The "what to do's" about the relative age effect will also be described.

When it comes to strength, power, endurance and speed, early maturers tend to have an advantage, particularly in sports where body mass is advantageous; therefore, they are able to out match their peers due to their body structure, not their talent or ability. As a result, they tend to have early success and in turn receive recognition and reinforcement from their coach(s).

The concern is not only for the late maturers, but also for the early maturers. Once the average and late maturers catch up, the early maturers are left feeling frustrated as they have always relied on their advanced developmental age and, as a result, some did not develop the necessary skills or fitness. Unfortunately, the early maturers often leave the sport around the age of 14 or 15 due to frustration (Lawrence, 1999).

Conversely, late maturing athletes tend to experience failure at an early age, as some of their early maturing peers are biologically superior. Although they train hard, they cannot keep up physically and are often disregarded by coaches; therefore, experiencing a lack of recognition and encouragement.

"Unfortunately, in developmental sport programs, we often don't allow late maturers the time to let their physical maturity catch up and their skills develop. Instead, children often leave the sport early because of lack of success and extreme frustration. This seems to hit the late maturing boys the hardest because they are at an extreme disadvantage. Ironically, they could have the potential to be better athletes, but we have to keep them involved in quality sport programs at the younger ages to make sure they continue with their skill development" (Lawrence, 1999).

Advanced Knowledge - Relative Age

Relative age also plays an important role in coaching decisions. "The relative age effect describes the observation that greater numbers of performers born early in a selection year are over-represented in junior and senior elite squads compared with what might be expected based on national birth rates". This means that a child born on January 1st may participate in the same programs as a child born on December 31st of the same year, although one is almost a year older than the other. It is well documented that relative age has a great advantage in athletic selections. The age group cut-off date for entry into organized youth sport is August 1st in English school sports and January 1st in Canadian ice hockey. In many different sports the relative age effect is clear to see. The tables in Appendix 1 show birth dates in male squads for athletics, football (soccer), swimming and tennis in English sports (Morris and Nevill, 2006). The bias towards autumn birthdays is striking, as well for the first quarter of the year in ice hockey.

If relative age, a 10-12 month difference, can have such a big impact on selection, participation and performance, it is quite obvious that the domain of early and late maturers needs very special attention, which points out the possible 4-5 years of maturation differences. Thus, the understanding of the maturation process and its consequences is crucially important for athletes, coaches, parents, teachers and sport administrators.

The Canadian Sport for Life (CS4L) document (Balyi, Way, Norris, Cardinal & Higgs, 2005) describes the patterns of growth and development and identifies the differences between chronological and developmental age. The terms "growth" and "maturation" are often used together and sometimes synonymously; however, each refers to specific biological activities.

Growth refers to observable step-by-step changes in quantity and measurable changes in body size such as height, weight, and fat percentage. Maturation refers to qualitative system changes, both structural and functional, in the body's progress toward maturity such as the change of cartilage to bone in the skeleton.

Long-Term Athlete Development (LTAD) requires the identification of early, average and late maturers in order to help to design appropriate training and competition programs in relation to optimal trainability and readiness. The beginning of the growth spurt and the peak of the growth spurt are very significant in LTAD applications to training and competition design.

Specific disabilities may dramatically change the timing and sequence of childhood and adolescent development. This must be considered when working with athletes with a disability.

Peak Height Velocity (PHV) is the fastest rate of growth during the adolescent growth spurt. Figures 3 and 4 illustrate PHV for girls and boys respectively, pointing out the differences between them. The charts also identify secondary sex characteristics with relation to growth.

Figure 2. Maturation in Girls and Boys (Adapted and modified from Tanner, 1973)

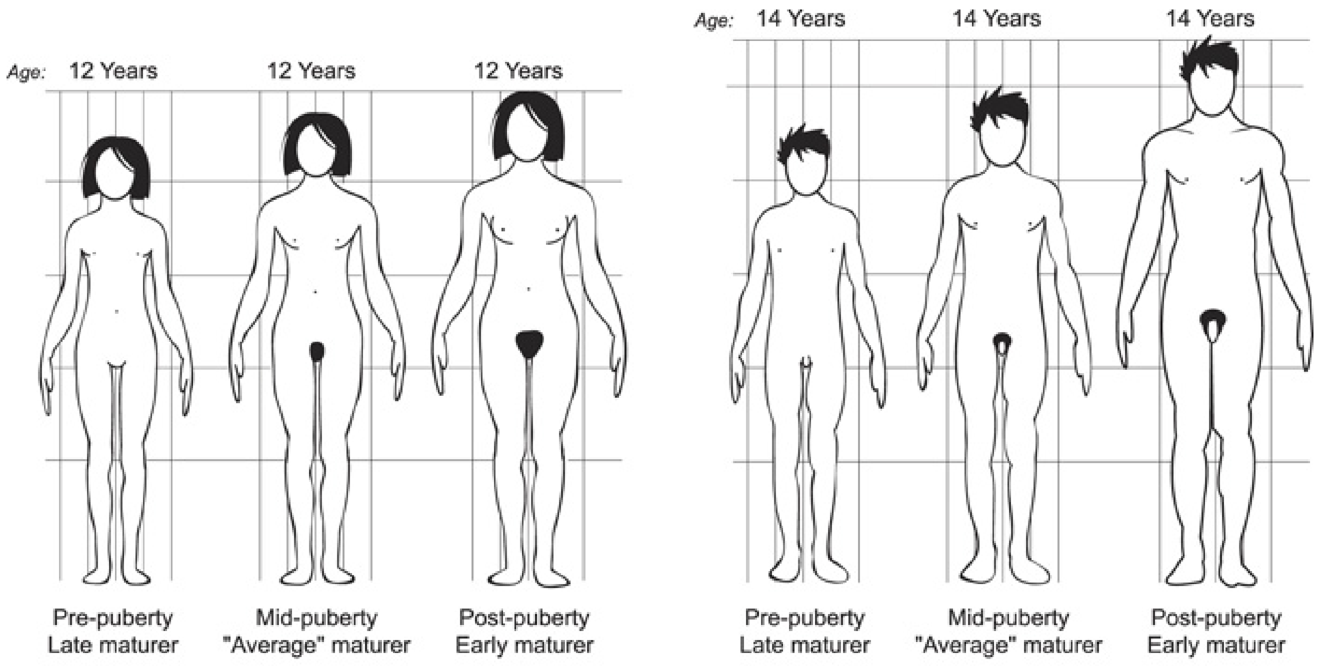
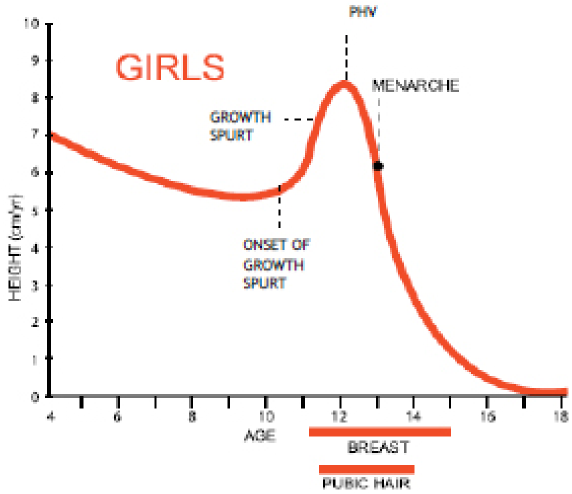
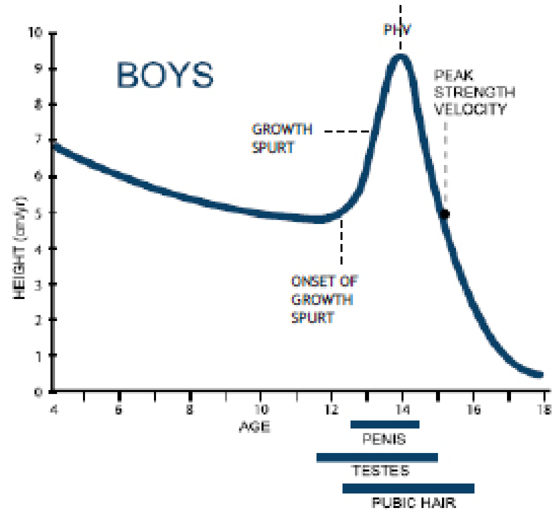


Figure 3. Maturity Events in Girls (Modified after Ross & Marfell-Jones, 1991)



"PHV in girls occurs at about 12 years of age. Usually the first physical sign of adolescence is breast budding, which occurs slightly after the onset of the growth spurt. Shortly thereafter, pubic hair begins to grow. Menarche, or the onset of menstruation, comes rather late in the growth spurt, occuring after PHV is achieved. The sequence of developmental events may normally occur two or even more years earlier or later than average" (Ross & Marfell-Jones, 1991).

Figure 4. Maturity Events in Boys (Modified after Ross & Marfell-Jones, 1991)



"PHV in boys is more intense than in girls and on average about two years later. Growth of the testes, pubic hair, and penis are related to the maturational process. Peak Strength Velocity (PSV) comes a year or so after PHV. Thus, there is pronounced late gain in strength characteristics of the male athlete. As with girls, the developmental sequence for male athletes may occur two or more years earlier or later than average. Early maturing boys may have as much as a four year physiological advantage over their late-maturing peers. Eventually, the late maturers will catch up when they experience their growth spurt" (Ross & Marfell-Jones, 1991).

Three Gymnasts the Same Chronological Age!

Trainability

The CS4L document also describes the various stages of LTAD and identifies the windows of optimal trainability related to the sensitive periods of the maturation process. Thus, windows of trainability refer to periods of accelerated adaptation to training during the sensitive periods of pre-puberty, puberty and early post-puberty. The window is fully open during the sensitive periods of accelerated adaptation to training and partially open outside of the sensitive periods. The windows are always open and never fully close (i.e. all systems are always trainable!).

The five S's of training and performance are used as a template to describe the windows of trainability. The trainability of speed, skill and suppleness (flexibility) is based on chronological age; however, the trainability of strength and stamina (endurance) is based on developmental age (the moving scales of the individual tempo of maturation). The trainability of these important S's will require different training programs designed for early, average and late maturers. Such programs should "react" to the individual tempo of maturation (see Appendix 2). By identifying the tempo of growth through metric measurements, training, competition and recovery programs can be adjusted to individual needs. Aerobic emphasis should begin at the onset of PHV (sport-specific requirements will define if it is a minor or major emphasis; see Appendix 3 for sport-specific energy system requirements), while the beginning of maximal strength training should begin after PHV (Ross & Marfell-Jones, 1991; Beunen & Homis, 2000; Balyi & Ross, 2009a; Balyi & Ross, 2009b). Therefore, the technique of measuring growth is very important and should be well defined with a protocol which is simple and reliable to ensure coaches and parents can do the monitoring.

Advanced Knowledge - Measuring Growth

Coaches and parents can use stature measurements (height) before, during, and after maturation as a guide for tracking the developmental age of children. Tracking allows coaches to address the sensitive periods of physical development (endurance, strength, speed and flexibility) and skill development. The age of an athlete can be examined from six different perspectives:

- Chronological age
- Developmental age
- Skeletal age
- General training age
- Sport-specific training age
- Relative age

Phase 1: Chronological age 0 to 6
- Very rapid growth.
- Measure standing height and weight on birthday.

Phase 2: Age 6 to the Onset of the growth spurt
- Steady growth until the onset of the growth spurt.
- Measure standing height and weight every three months.
- If measurement takes place outside of home, replace birthday with the starting point of the annual training and competition cycle.

Phase 3: From the onset of growth spurt to peak of PHV
- Rapid growth until peak is reached.
- Measure standing height, sitting height and arm span every three months.

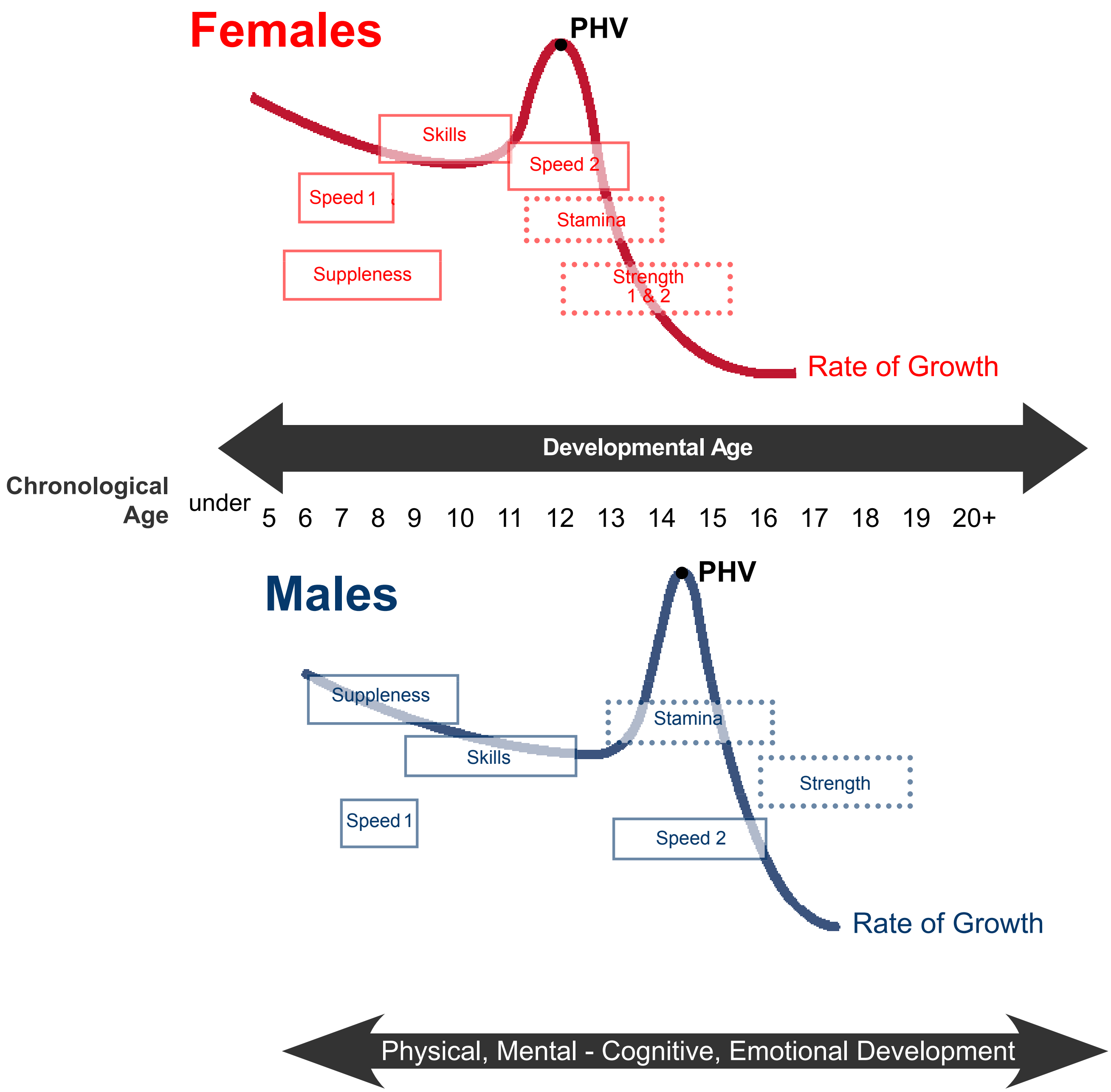
Phase 4: PHV to Slow Deceleration
- Rapid deceleration.
- Measure standing height, sitting heights, and arm span every three months.

Phase 5: From Slow Deceleration to Cessation
- Slow deceleration of growth until cessation of growth.
- Measure standing height every months.

Phase 6: Cessation
- Cessation of growth.
- Measure height and weight on birthday.

The graph below shows the approximate timing of the sensitive periods of trainability in females and males. Exact timing will vary as a function of the individual onset of PHV. Note that boxes with solid lines represent sensitive periods that are chronological age based. Boxes with dashed lines represent sensitive periods that are on a “moving scale”, that is, they are related to the onset of PHV, PHV and as growth decelerates (Balyi et al, 2005).

Figure 5. Windows of Accelerated Adaptation to Training (Balyi and Way, 2005)



The Six Phases of Growth

In order to track growth, data must be collected on a longitudinal basis, with the analysis of models and graphs (Balyi & Ross, 2009a; Balyi & Ross, 2009b). PHV is the fastest rate of growth during the adolescent growth spurt; it can be used as a guide to growth and physical maturity during adolescence, and can be used to identify the maximum growth rates of children. Somatic (musclo-skeletal) growth follows six phases:

Phase 1: Chronological age 0 to 6
This phase is characterized by very rapid growth during infancy and very rapid deceleration after age two. It is recommended that measurement of standing height and weight are carried out every birthday.

Phase 2: Age 6 to the onset of the growth spurt
This phase is characterized by steady growth (an average of 5-6 cm per year). It is recommended that measurement of standing height, sitting height and arm span are carried out at every birthday. If measurements take place in a club, do the first measurement of the year at the beginning of the annual season. Once the onset of PHV is identified, start to take measurements of standing height, sitting height and arm span quarterly (every three months).

During this phase the sensitive periods for skill, speed and suppleness should be identified by chronological age.

Phase 3: From the onset of GS to PHV
This phase is characterized by rapid growth. In the first year of the spurt the average growth is 7 cm and then about 9 cm in the second year in boys and roughly 6 and 8 cm in girls (Tanner, 1989). It is recommended that measurements of standing height, sitting height and arm span are recorded quarterly in order to monitor which part of the body is growing the fastest. The change in the centre of gravity, leg length and arm span will help the coach understand the process better; i.e., the athlete/player is losing coordination and speed due to rapid growth, etc.

During this phase the aerobic capacity window should be identified by the onset of PHV and the second sensitive period for speed by chronological age (Balyi & Ross, 2009a; Balyi & Ross, 2009b; Stafford, 2005).

Phase 4: From PHV to slow deceleration
This phase is characterized by rapid deceleration; about 7 cm in boys and 6 cm in girls in the first year after the peak and 3 cm in next year (Tanner, 1989). It is recommended that measurements of standing height, sitting height and arm span are taken quarterly to monitor deceleration.

During this phase, the sensitive period for aerobic power and strength can be identified after deceleration, as it was described earlier. That is to say, aerobic power should be trained after PHV of PHV. In terms of females, strength training can be priorized immediately after PHV or at the onset of the menarche. For males, strength training should be a priority 12–18 months after PHV (Ross & Marfell-Jones, 1991; Beunen & Thomis, 2000; Anderson & Bernhardt, 1998).

Phase 5: From slow deceleration of growth to cessation of growth
Slow deceleration will start one to two years after PHV and will end with cessation of growth (Tanner, 1989).

It is recommended that training loads and intensities be determined gradually by diagnostics. Since all systems now are fully trainable, testing will identify individual and team training priorities.

Phase 6: Cessation of growth
During this phase it is recommended that the individual diagnostics of the strengths and weaknesses of the athlete/player determine training loads and intensities.

Thus, the biological markers of the onset of PHV, PHV and the onset of menarche monitored by the described measurements should allow the coach to optimize training for the pubescent athlete and the coach should use the opportunity provided by the sensitive periods of accelerated adaptation training.

How to Measure PHV (Williams, 2009a; Williams, 2009b)

Tools and equipment for measuring:

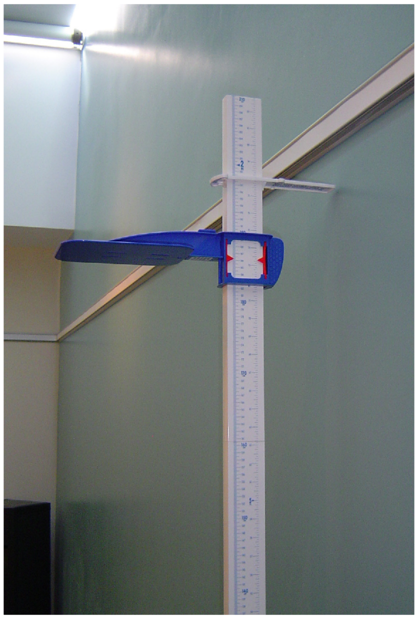
When considering the equipment needed for measurement, one must look at how much emphasis is going to be put on the measurement of stature. If stature data is going to be heavily incorporated into training plans, data must be very accurate, and thus, the more expensive the purchased equipment should be.

Ideal equipment:
- A free standing or wall mounted stadiometer
- This stadiometer would need to have sliding headboards and a dial or digital (or digital read outs, which would aid in the ease of use

Acceptable equipment includes:
- An anthropometer or retractable steel measuring tape
- A headboard
- A smooth floor with a straight flat wall at 90 degrees

Unacceptable equipment includes:
- A cloth measuring tape
- Flexible material
- Carpeted floor
- An uneven floor
- No backboard

Figure 6. Example of a Free Standing Stadiometer



Why is Measurement Accuracy so Important?

As previously mentioned, proper technique when measuring an athlete is extremely important, as random and measurement errors are common. It is the responsibility of the person measuring to ensure such errors are minimized, as the more errors there are, the harder the results will be to interpret. Similarly, the more errors there are the less value the results will have. To decrease error, ensure:

- The environment is consistent and controlled
- Clothing is consistent and not bulky
- Feet are bare
- You have the cooperation of the athletes
- You follow standardized and consistent procedures

What to Measure?

Determining the rate of growth is dependent on accurate measurements; therefore, measurements need to be made to the nearest 0.1 cm. Each athlete should be measured and recorded twice, but these measurements should not differ by more than 0.4 cm. If they do not differ by more than 0.4 cm, the mean of the two measurements should be taken. If they do differ by more than 0.4 cm, a third measurement should be taken, and the median of all three measurements should be calculated (Williams, 2009a).

How Should Growth be Measured?

When measuring a child's height, it is important to pay special attention to technique, if the results are to be of use. Ideally, two measurers should be present; one to perform the positioning of the athlete, while the other records the measurement. If a second measurer is not available, it is still possible to get valid results; however, extra attention to technique should be paid.

For proper measurement of height refer to Figure 7.

The orbitale (O) is located on the lower or most inferior margin of the eye socket. The tragion (T) is the notch above or superior to the tragus or flap of the ear, at the superior aspect of the zygomatic bone. This position corresponds almost exactly to the visual axis when the subject is looking directly ahead.

Example 1
Two measurements within 0.4 cm of each other

Stature measurement #1	166.2 cm
Stature measurement #2	166.3 cm

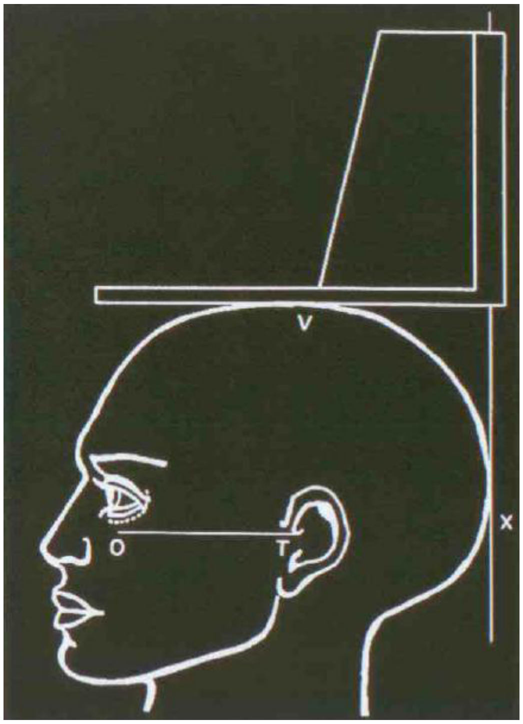
The above two measurements are within the acceptable range and the mean measurement recorded as 166.3 cm.

Example 2
Two measurements **not** within 0.4 cm of each other

Stature measurement #1	158.2 cm
Stature measurement #2	162.9 cm
Stature measurement #3	162.6 cm

The above two measurements are not within 0.4 cm of each other; therefore, the median of the three scores needs to be used and the recorded score is 162.6 cm.

Figure 7. Orientation of the Head in the Frankfort Plane (Ross, Carr & Carter, 2000)



Protocol for Sitting Height Measurement (Simmons, 2000)

- Student sits on the base of the stadiometer with knees slightly bent. Hands rested on knees.
- The buttocks and shoulders rest lightly against the stadiometer, which is positioned vertically behind the student. Ensure there is no gap between buttocks of student and stadiometer.
- The tester applies gentle upwards traction to the skull behind the ears to ensure the trunk is fully stretched.
- Draw down the measuring bar to the students head and record sitting height to the nearest 0.1 cm.
- Once sitting height is calculated, it can be subtracted from the stature score, in order to derive the leg length height.

Figure 8. Measuring Sitting Height

Protocol for Standing Height Measurement (Simmons, 2000)

- The student stands erect in bare feet with heels, buttocks and shoulders pressed against the stadiometer.
- The heels are together with arms hanging freely by the side (palms facing thighs).
- The tester applies gentle upward traction to the skull behind the ears.
- The student looks straight ahead, takes a deep breath and stands as tall as possible.
- Draw down the measuring bar to the student's head and record standing height to the nearest 0.1 cm.

Figure 9. Measuring Standing Height

Protocol for Arm Length Measurement (Simmons, 2000)

- Mount a tape measure on the wall about shoulder height of the students being tested. Ensure the starting point of the tape measure is fixed to a corner of a wall. This is where the student's fingers must be fixed.
- The student stands erect with their stomach and toes facing the wall, feet together and head turned to the right.
- The arms are extended laterally at shoulder level (horizontal) with palms facing forwards. Fingers stretched.
- The tip of the middle finger is aligned with the beginning of the tape measure (corner of wall) and arms are out-stretched along the tape measure.
- Use a ruler held vertically to the tape measure to record total arm span to the nearest 0.1 cm.

Figure 10. Measuring Arm Span

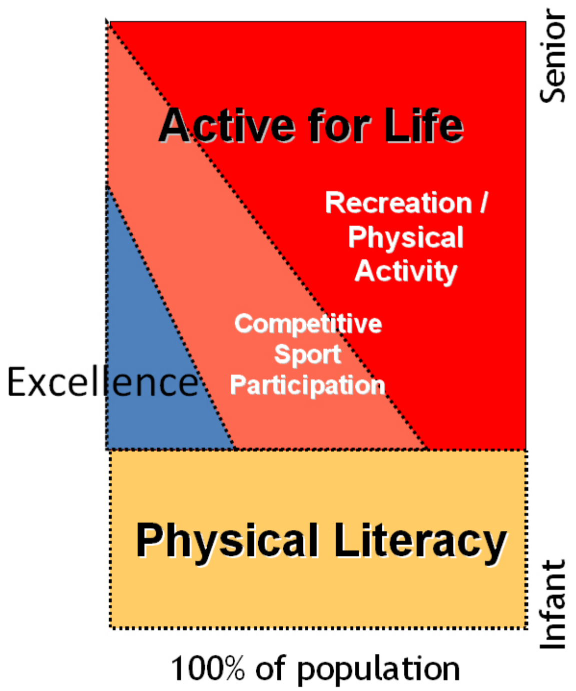
Ethical and Sensitivity Issues (Williams, 2009a; Williams, 2009b)

When conducting the measurement of growth, it is important to realize the ethical and sensitivity issues surrounding the measurement and monitoring of a child's development.

Coaches must understand not only the physical changes to a child's shape and size, but also the implications they can have on personality and the child's perception of their own body, as well as other people's perception of their body. Coaches are in a unique place, in that they can offer good advice and educate their athletes in a sensitive and appropriate manner.

(See CS4L Physical, Mental, Cognitive and Emotional Development at www.canadiansportforlife.ca)

Figure 11. Life-cycle of Physical Activity and Sport



When Should Growth be Measured?

It is important that coaches or support staff do not become consumed by the number of times the height is recorded for three reasons:

1. The athlete may become bored.
2. The athlete may become preoccupied with the measurements, particularly if they perceive they are not growing as fast as their peers.
3. Intervals between testing periods need to be long enough to allow for substantial growth, over and above what would be expected to occur through measurement error (Williams, 2009a).

It is recommended:

- Measurements are made once quarterly.
- Measurements are made as close as possible to the same date in the month and also at the same time of day.
- Part of a training session be set aside for measurements.
- Measurements are taken after a day of rest (this will ensure there are no confounding effects of training from the previous day).
- Measurements are taken at the beginning of the training session as the athlete will not be prone to any effects from training session (i.e. stretching, bouncing, drop jumps etc. can all have an impact on stature) (Williams, 2009a).

Even if the coach thinks the child has already started their pubertal growth spurt, the serial measurements, taken over a year, will determine if the athlete is past the stage of PHV. The earlier the measurements can occur, prior to the growth spurt, the greater the opportunities are for the coach to adjust the training program, according to growth rate. As PHV is occurs at typically 12 years for females and 14 years for males, it would be beneficial to have as many measurement points as possible prior to this age.

Table 1. Typical Growth from Year to Year Starting at Age Five (see Figure 12 on the next page)

Year	6	7	8	9	10	11	12	113	14	15	16	17	18	19	20
Ht (cm)	5.0	4.8	5.0	4.8	5.0	4.8	8.6	12.0	7.7	3.3	2.3	1.9	1.3	0.9	0.5

Determining a Velocity Curve

To determine the velocity curve, the increase in stature from one measurement time period to the next consecutive measurement time period is subtracted one from the other. For example, in Table 1 from 9 to 10 years the increase in stature is 5 cm.

By plotting the velocity curves it will be possible to clearly distinguish the rate of growth from one point in time to another. The velocity curve will immediately show distinctive growth points (for example, the onset of the acceleration in the curve, the peak in the curve and the deceleration in the curve).

How to Use the Growth Information

Measuring PHV is a tool to track growth. Monitoring growth velocity curves and recognizing the timing and tempo of growth is essential for coaches when training adolescent athletes (pre-pubertal and pubertal). Monitoring growth and plotting the patterns of growth can help coaches decide how to adjust training, competition and recovery programs according to the velocity of growth. Although the trainability of skill, speed and suppleness is based on chronological age (Viru, 1995; Viru et al., 1998); Balyi & Ross, 2009a; Balyi & Ross, 2009b; Rushall, 1998), biological markers can identify the sensitive periods of trainability to exploit the adaptation to training for stamina and strength. Thus, the timing of the training emphasis can be determined to induce optimal training effects. The onset of PHV will mark the beginning of the emphasis of aerobic training in aerobic sports, the implementation of continuous training methods (LSD and Fartlek) between the onset of PHV and PHV and interval training after PHV (after growth decelerates) (Lawrence, 1999; Kobayashi et al., 1978; Rushall, 1998; Vorontsov, 2002). This emphasis will be different in speed and power sports and the extent of the emphasis should be designed by sport-specific norms and needs; i.e., “How much endurance is enough?” (See Appendix 3 for sport-specific energy system requirements).

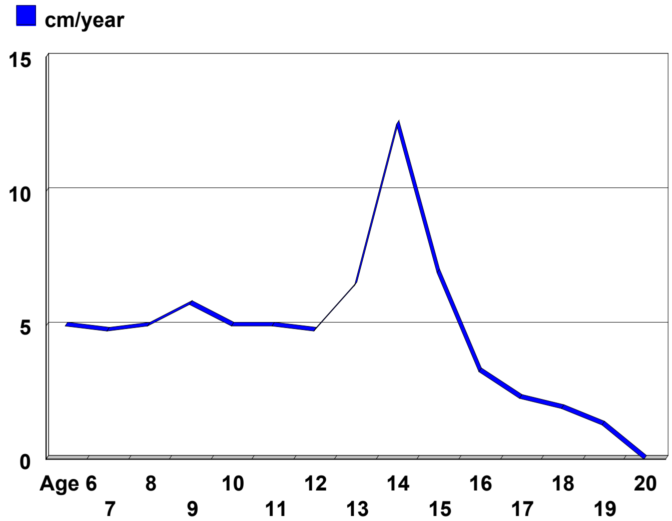
For female athletes accelerated adaptation to strength training occurs immediately after PHV and/or with the onset of menarche (strength training is central nervous system and motor improvements before full hormonal maturation, and no hypertrophy is expected), and 12–18 months after PHV for males (Ross & Marfell-Jones, 1991; Beunen & Thomis, 2000; Anderson & Bernhardt, 1998). Again, sport-specific norms will define the extent of the strength training emphasis, thus, “How much strength is enough” in endurance sports and speed and power sports respectively?

Both stamina and strength should be trained at all stages, but the emphasis will be defined by the objectives of the different stages and the individual tempo of growth (see CS4L and sport-specific LTAD models).

Measuring standing height, sitting height and arm span quarterly after the onset of the PHV will help to determine what part of the body is growing and at what velocity (this usually begins with the feet and hands, followed by the legs, then the arms, and finally the trunk). This way the coach will have a better understanding of the impact of growth on skill, on speed and on flexibility.

Thus, program planning (periodization) will “react” to the patterns of growth to define the training programs versus improvising decision making on these crucial issues. To summarize, when planning and designing programs for adolescent athletes, developmental age should be used at the point of reference, as opposed to chronological age.

Figure 12. The Rate of Growth or ‘Growth Velocity Curve’ of a Boy Charted from 6-20 Years of Age, Based on Table 1



Conclusion

Monitoring growth before, during and after the adolescent growth spurt is very important for coaches to be able to create an individualized plan to optimize athletes' development. The following is a summary to guide coaches as they monitor their athletes and develop training, competition and recovery programs for their long-term development.

- Growth measurements are needed to monitor growth.
- The onset of PHV, PHV and the onset of menarche should be determined in order to be able to adjust training, competition and recovery programs according to the tempo of growth.
- Plotting growth will help to identify the onset of the growth spurt, and the peak of the growth (after growth decelerates).
- The onset of the menarche is about a year after growth decelerates, thus the coach can estimate the time of the onset of menarche.
- Before the onset of the growth spurt standing height should be measured on every birthday, or at the beginning of the annual training cycle in clubs.
- Standing height, sitting height and arm span should be measured quarterly after the onset of the growth spurt.
- Training skill, speed and suppleness is based on chronological age, while stamina and strength are based the adolescent growth spurt.

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Glossary of Terms

Adaptation refers to a response to a stimulus or a series of stimuli that induces functional and/or morphological changes in the organism. Naturally, the level or degree of adaptation is dependent upon the genetical endowment of an individual. However, the general trends or patterns of adaptation are identified by physiological research, and guidelines are clearly delineated of the various adaptation processes, such as adaptation to muscular endurance or maximum strength.

Adolescence is a difficult period to define in terms of the time of its onset and termination. During this period, most bodily systems become adult both structurally and functionally. Structurally, adolescence begins with an acceleration in the rate of growth in stature, which marks the onset of the adolescent growth spurt. The rate of statural growth reaches a peak, begins a slower or decelerative phase, and finally terminates with the attainment of adult stature. Functionally, adolescence is usually viewed in terms of sexual maturation, which begins with changes in the neuroendocrine system prior to overt physical changes and terminates with the attainment of mature reproductive function.

Age

- **Chronological age** refers to the number of years and days elapsed since birth. Children of the same chronological age can differ by several years in their level of biological maturation.

- **Skeletal age** refers to the maturity of the skeleton determined by the degree of ossification of the bone structure. It is a measure of age that takes into consideration how far given bones have progressed toward maturity, not in size, but with respect to shape and position to one another.

- **Relative age** refers to differences in age among children born in the same calendar year (Barnsley and Thompson, 1985).

- **Developmental age** refers to the degree of physical, mental, cognitive, and emotional maturity. Physical developmental age can be determined by skeletal maturity or bone age after which mental, cognitive, and emotional maturity is incorporated.

- **General training age** refers to the number of years in training, sampling different sports.

- **Sport-specific training age** refers to the number of years since an athlete decided to specialize in one particular sport.

Ancillary Capacities refer to the knowledge and experience base of an athlete and includes warm-up and cool-down procedures, stretching, nutrition, hydration, rest, recovery, restoration, regeneration, mental preparation, and taper and peak.

The more knowledgeable athletes are about these training and performance factors, the more they can enhance their training and performance levels. When athletes reach their genetic potential and physiologically cannot improve anymore, performance can be improved by using the ancillary capacities to full advantage.

Biological Markers are the onset of PHV, PHV and the onset of menarche.

Childhood ordinarily spans the end of infancy — the first birthday — to the start of adolescence and is characterized by relatively steady progress in growth and maturation and rapid progress in neuromuscular childhood, which includes pre-school children aged 1 to 5 years, and late childhood, which includes elementary school-age children, aged 6 through to the onset of adolescence.

Development refers to "the interrelationship between growth and maturation in relation to the passage of time. The concept of development also includes the social, emotional, intellectual, and motor realms of the child."

The terms "**growth**" and "**maturation**" are often used together and sometimes synonymously. However, each refers to specific biological activities. Growth refers to "observable, step-by-step, measurable changes in body size such as height, weight, and percentage of body fat." Maturation refers to "qualitative system changes, both structural and functional in nature, in the organism's progress toward maturity; for example, the change of cartilage to bone in the skeleton."

Fartlek is the Swedish word for "speed-play" which means alternating faster and slower running.

LSD is long slow distance running.

Peak Height Velocity (PHV) is the maximum rate of growth in stature during the growth spurt. The age of maximum velocity of growth is called the age at PHV.

Physical literacy refers to the mastering of fundamental motor skills and fundamental sport skills.

Puberty refers to the point at which an individual is sexually mature and able to reproduce.

Readiness refers to the child's level of growth, maturity, and development that enables him/her to perform tasks and meet demands through training and competition. Readiness and sensitive periods of trainability during growth and development of young athletes are also referred to as the correct time for the programming of certain stimuli to achieve optimum adaptation with regard to motor skills, muscular and/or aerobic power.

Sensitive periods of accelerated adaptation to training refer to readiness, when there is a physiological possibility for accelerated adaptation to training during pre-puberty, puberty and early post-puberty.

Somatic refers to the musculo-skeletal system.

Trainability refers to the genetic endowment of athletes as they respond individually to specific stimuli and adapt to it accordingly. Malina and Bouchard (1991) define trainability as "the responsiveness of developing individuals at different stages of growth and maturation to the training stimulus."

Appendix 1. It Also Matters When in the Year Your Child is Born

There can be serious advantages or disadvantages when athletes compete all year in the same age group based on their birth date. This is because, depending on when they are born, they may always be the oldest or the youngest.

Children who are always the oldest in their age group tend to be larger, stronger and more skilled than their younger teammates and, often, this causes coaches to believe they are overall better players. As a result, coaches often give them more attention and playing time; in the end, this tends to make them better players and provides them with more opportunities to advance to higher levels of play. These biased percentages have occured for over two decade (see Figure 13 below).

For example, in 2007, more than 13% of hockey players who played in major junior hockey were born in January while only 4% were born in December. This is called the relative age effect (for more info on the relative age see the Advanced Knowledge box on page 5).

Coaches, sport administrators and parents need to work with sports to find ways to reduce the relative age effect. One example of an easy change is to take the child's age on the date of the competition, rather than at the start of the competitive season.

Figure 13. Distribution of Birthmonths of Drafted Ontario Hockey League, Western Hockey League, and Quebec Major League Players (Barnsley, Thompson & Barnsley, 1985)

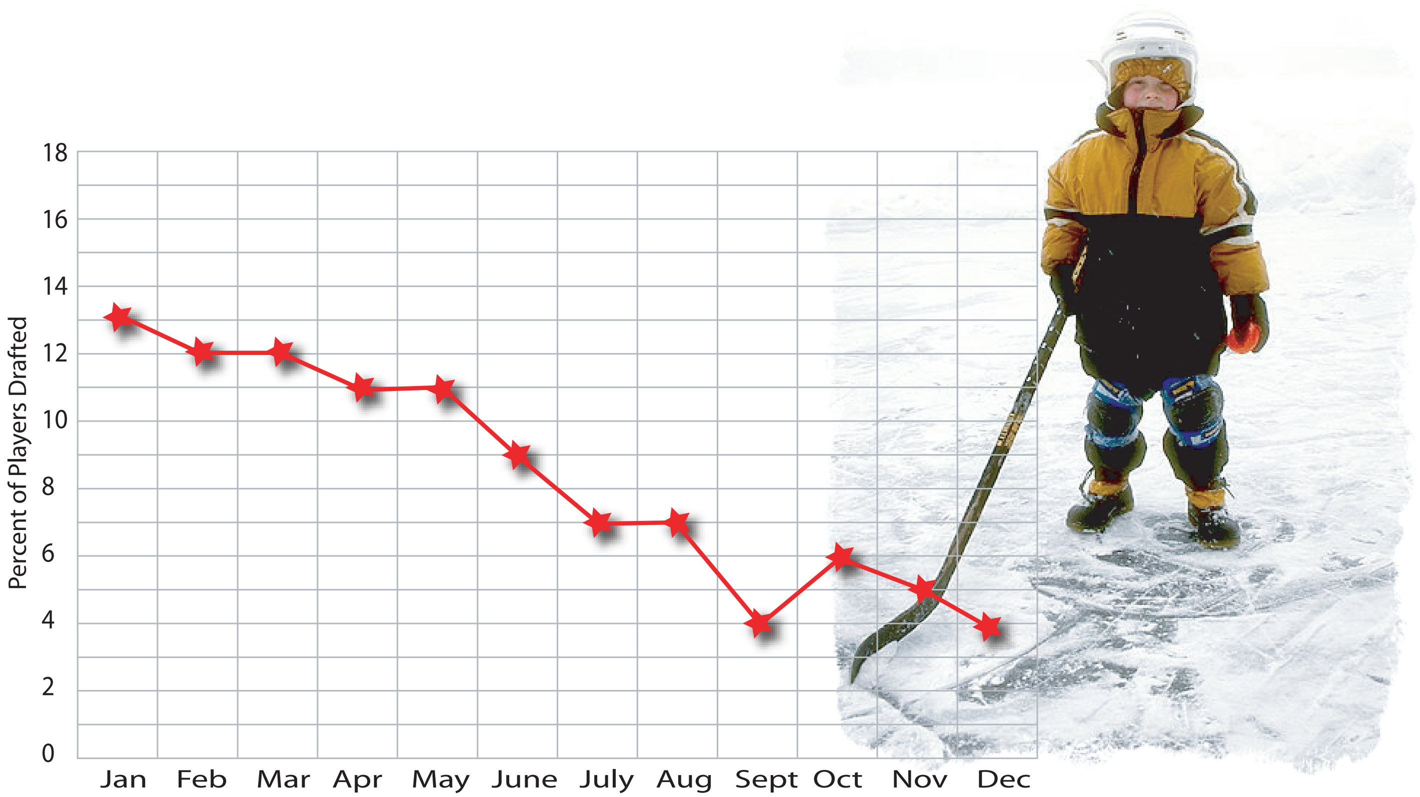
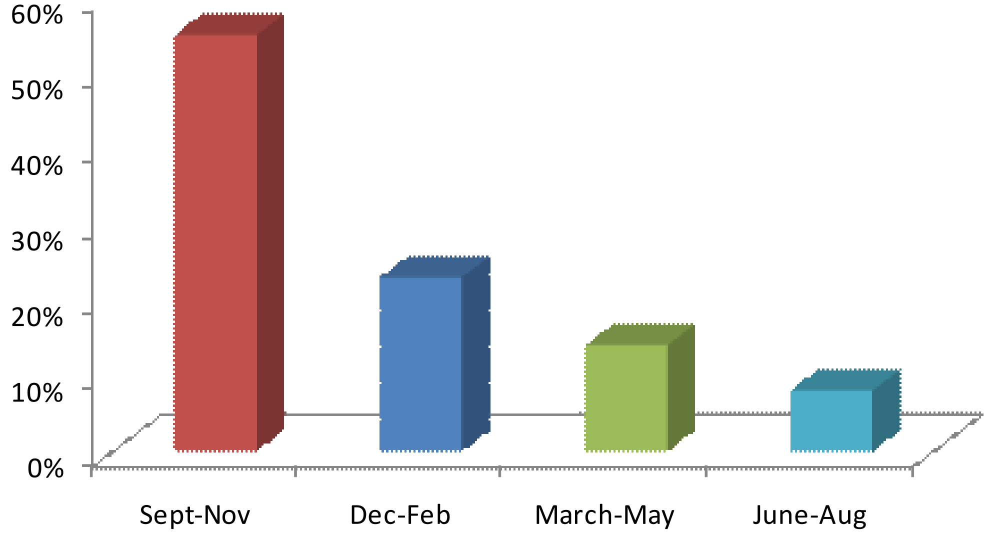
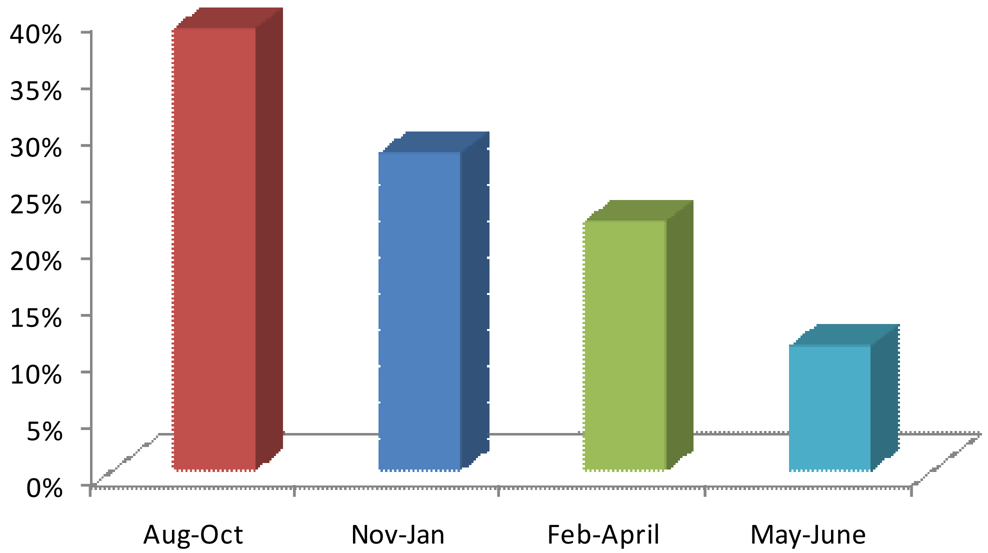


Figure 14. Evidence of a Relative Age Effect: U15 Male FInalists - English School Athletics (n=113) (Adapted and modified from Morris & Nevill, 2006)



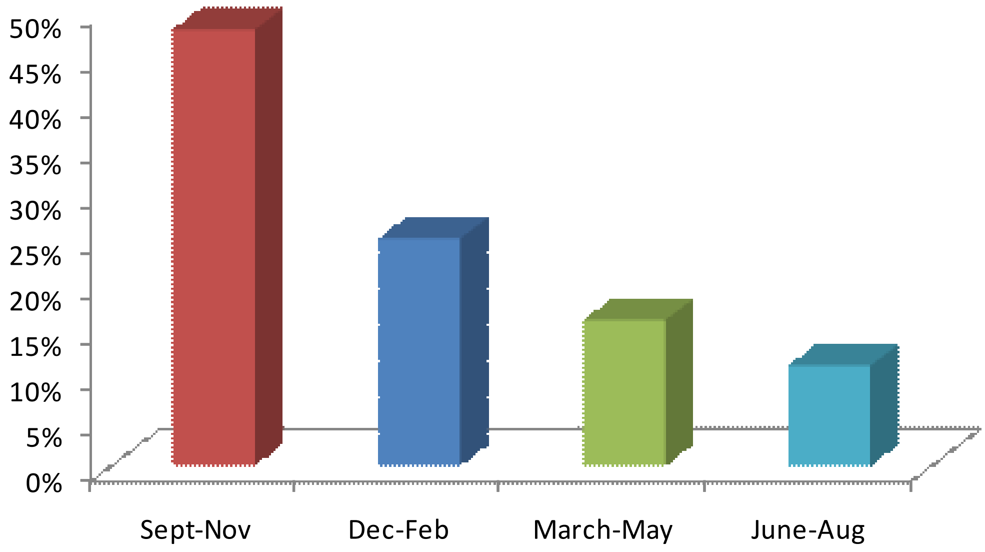
Sources: http:www.esaa.net; Whittingham & Matthews (Eds.) British Athletics Statistical Review 1999-2005

Figure 15. Evidence of a Relative Age Effect: ASA Male Age Championship Swimmers in 2004 (n=186) (Adapted and modified from Morris & Nevill, 2006)



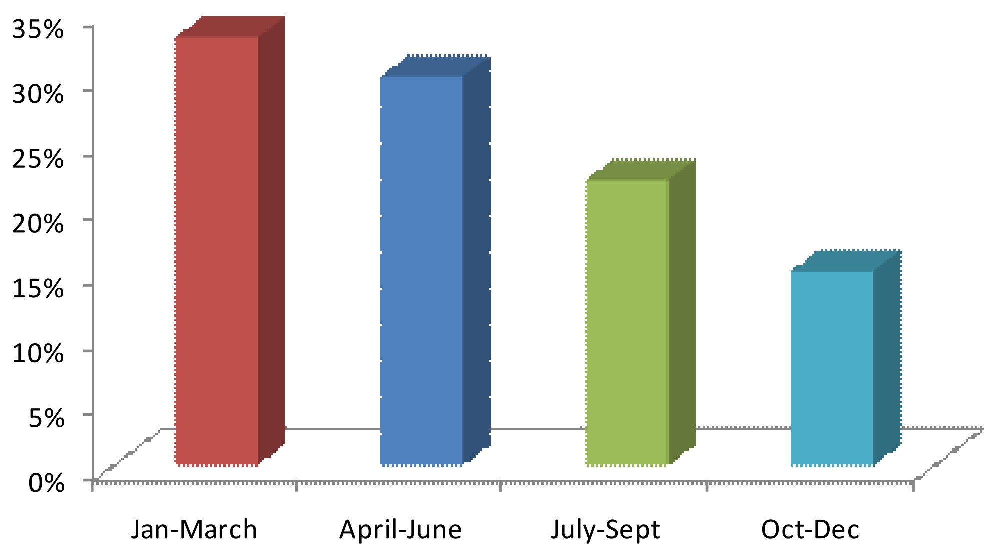
Sources: Amateur Swimming Association

Figure 16. Evidence of a Relative Age Effect: Male English Academy Soccer Players in 2002/2004 (n=1,765) (Adapted and modified from Morris & Nevill, 2006)



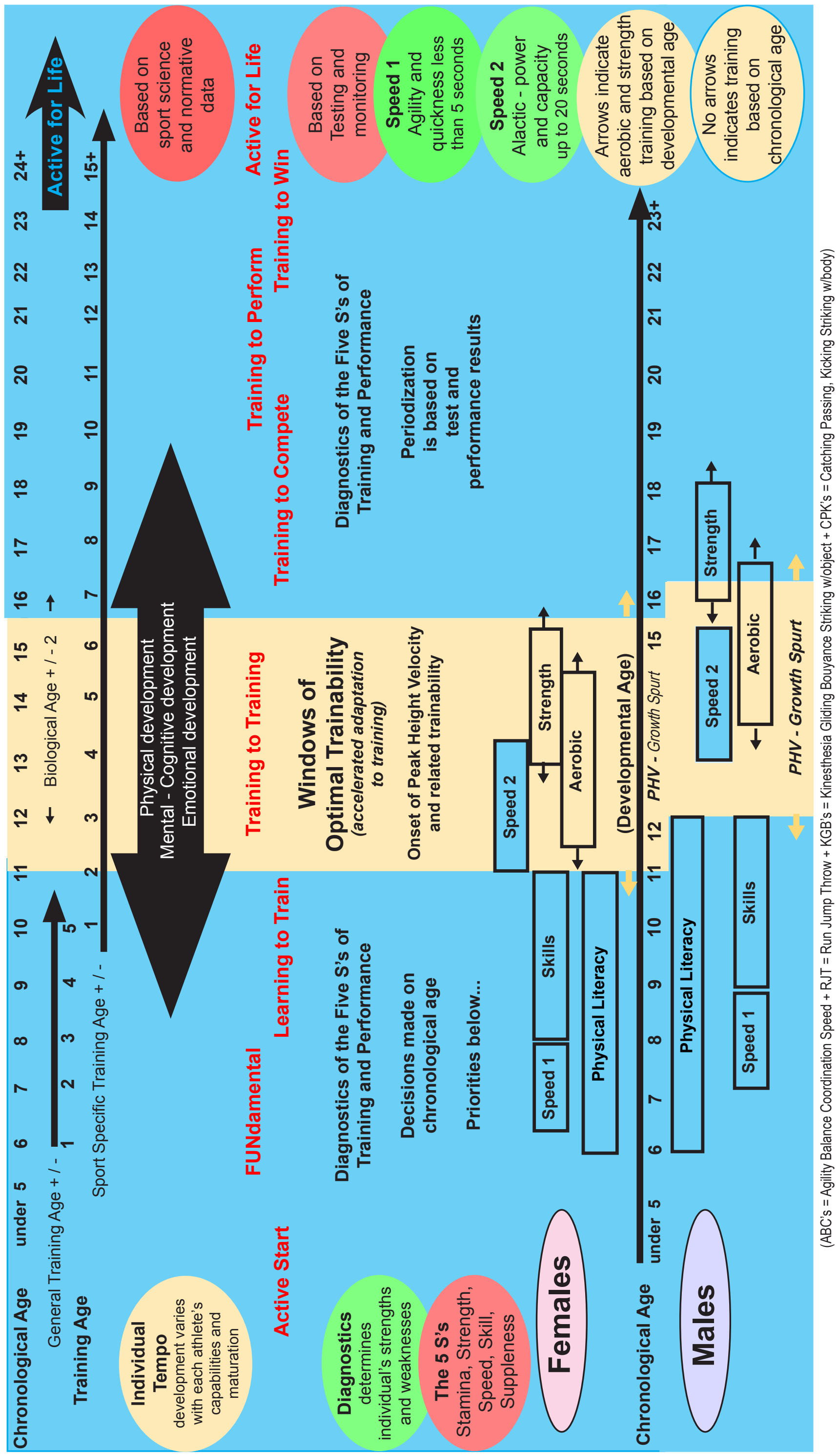
Sources: M. Hulse, The Football Association
Medical and Exercise Science Department

Figure 17. Evidence of a Relative Age Effect: Male Elite Junior Tennis Players in 2003 (n=237) (Adapted and modified from Morris & Nevill, 2006)



Source: Edgar and O'Donoghue, 2005

Appendix 2. Optimal Trainability (Balyi, Devlin, Lauzière, Moore and Way, 2006)



Appendix 3. Various Sports and Their Predominant Energy System (Adapted from Fox, Bowers & Foss, 1988)

	% Emphasis According to Energy Systems		
Sports or Sport Activity	ATP-PC & LA	LA-O_2	O_2
1. Baseball	80	20	-
2. Basketball	85	15	-
3. Fencing	90	10	-
4. Field Hockey	60	20	20
5. Football	90	10	-
6. Golf	95	5	-
7. Gymnastics	90	10	-
8. Ice hockey			
a. Forwards, defense	80	20	-
b. Goalie	95	5	-
9. Lacrosse			
a. Goalie, defense, attack men	80	20	-
b. Midfielders, man-down	60	20	20
10. Rowing	20	30	50
11. Skiing			
a. Slalom, jumping, downhill	80	20	-
b. Cross Country	-	5	95
c. Pleasure Skiing	34	33	33
12. Soccer			
a. Goalie, wings, strikers	80	20	-
b. Halfbacks or link men	60	20	20
13. Swimming & diving			
a. 50 yds, diving	98	2	-
b. 100 yds	80	15	5
c. 200 yds	30	65	5
d. 400, 500 yds	20	40	40
e. 1500, 1650 yds	10	20	70
14. Tennis	70	20	10
15. Track & field			
a. 100, 220 yds	98	2	-
b. Field events	90	10	-
c. 440 yds	80	15	5
d. 880 yds	30	65	5
e. 1 mile	20	55	25
f. 2 miles	20	40	40
g. 3 miles	10	20	70
h. 6 miles (Cross country)	5	15	80
i. Marathon	-	5	95
16. Volleyball	90	10	-
17. Wrestling	90	10	-

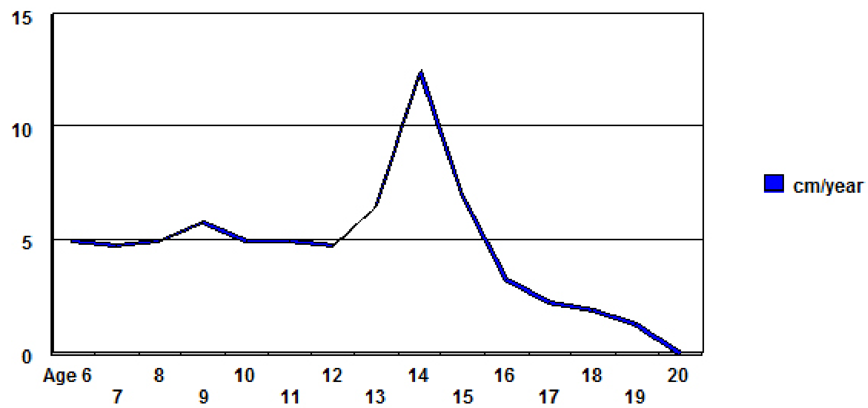
ATP-PC = Adenosine Triphosphate
LA = Lactic Acid System
O^2 = Oxygen System

Appendix 4. Tables for Plotting Annual and Quarterly Growth

Standing Height Example

Age	9	10	11				12				13				14			
Growth in cm	5	6	0.9	1.3	3	1	1.9	2.6	3.0	1.1	4.3	3.0	3.4	1.3	1.0	2.1	2.7	1.9
Total Growth in cm	5	6	6.2				8.6				12				7.7			

15				16				17				18				19				20			
2.1	1.6	1.3	2.0	1.4	0.7	0.9	1.0	1.1	0.5	0.6	1.0	0.7	0.3	0.5	0.6	0.4	0	0	0.4	0	0	0	0
7.00				4.00				3.2				2.1				0.8				0			

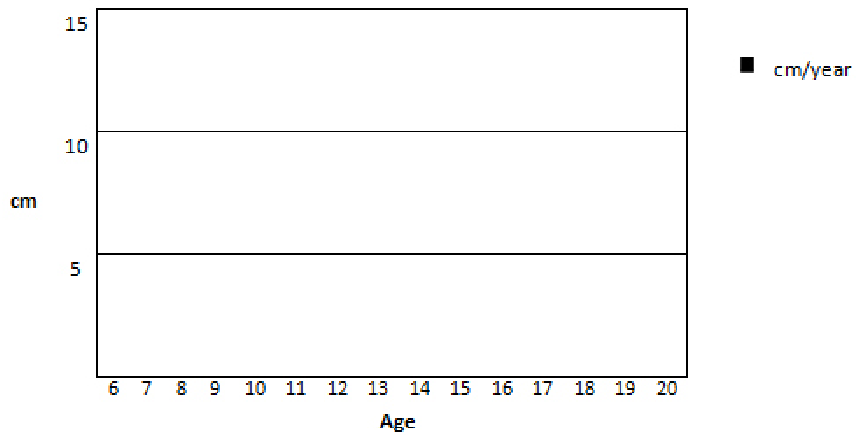


Standing Height

Age	9	10	11				12				13				14			
Growth in cm																		
Total Growth in cm																		

15				16				17				18				19				20			

Plotting the Growth Velocity Curve for Standing Height

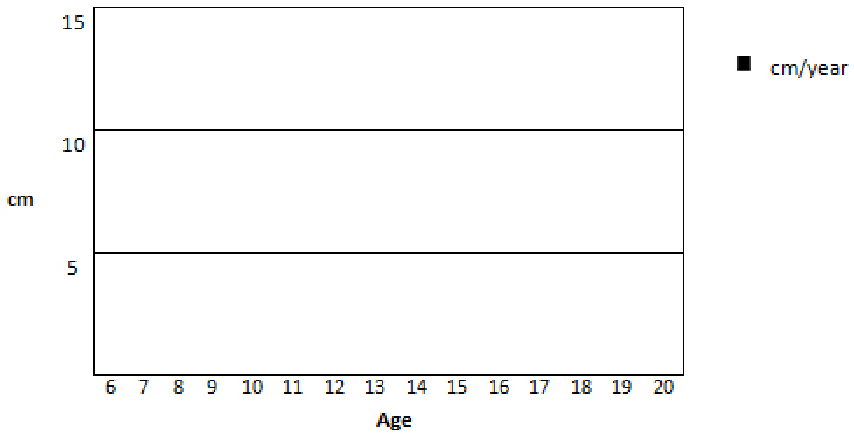


Sitting Height

Age	9	10	11	12	13	14
Growth in cm						
Total Growth in cm						

15	16	17	18	19	20

Plotting the Growth Velocity Curve for Sitting Height

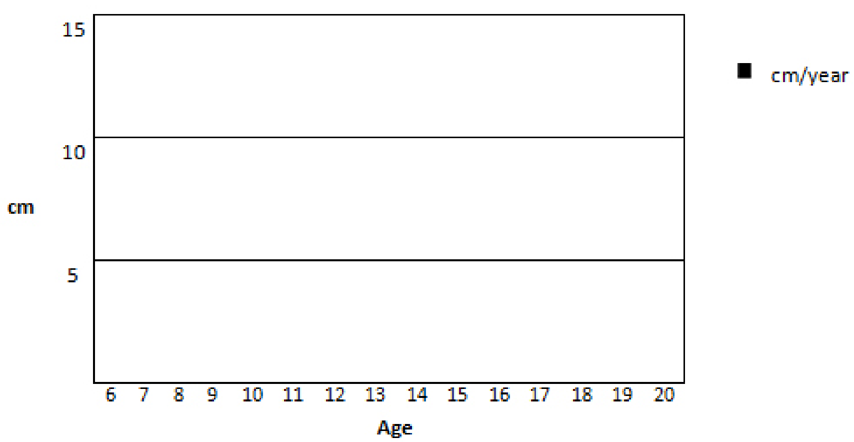


Arm Span

Age	9	10	11	12	13	14
Growth in cm						
Total Growth in cm						

15	16	17	18	19	20

Plotting the Growth Velocity Curve for Arm Span



Appendix 5. Phases of Measurement