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National Coaching Certification Program

coach.ca

Competition-Coaching Introduction Advanced (T2T)

Step 4:

Energy systems

Reference Material
for Dryland Workshop

PARTNERS IN COACH EDUCATION

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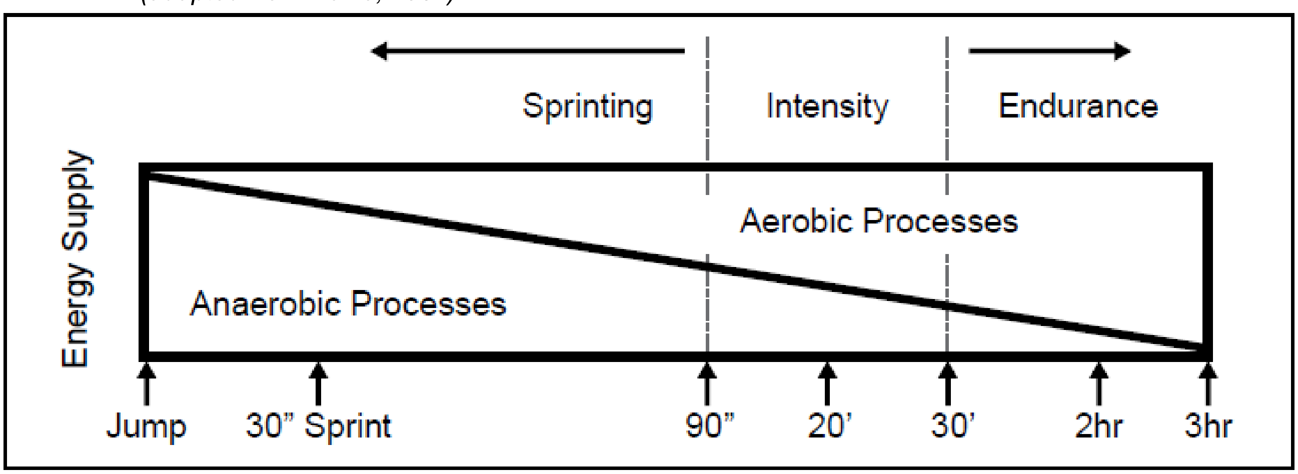
This section on Energy Systems expands on the information provided in section 4 of your Learning to Train (Dryland) Reference Material and is directed primarily at supporting you in your role working with athletes in the Training to Train stage of athlete development.

4.1 Energy Systems Overview

Recall that the body uses aerobic and anaerobic processes to create the energy required to do its work. These processes store energy in special molecules called adenosine triphosphate (ATP), which release their energy by being broken down during events like muscle contraction. The process of storing and releasing energy is cyclic; once broken down, ATP can reform during recovery via aerobic and anaerobic reactions. It is critical to note that aerobic and anaerobic processes are contributing to energy transfer during all movement. However, the relative contribution of each set of processes depends on the intensity and duration of the activity being performed.

As shown in Figure 4.1 below, aerobic processes make a growing contribution to an activity as its duration increases, while anaerobic processes contribute most to very short and intense activities. The table on the following page explains why this relationship exists by describing the basic characteristics of aerobic and anaerobic energy systems.

Figure 4.1: Relative Contributions of Aerobic and Anaerobic Processes to Activities of Various Durations (adapted from Harre, 1982)



During the Training to Train (T2T) stage of athlete development the energy systems' power and capacity increase rapidly. This is particularly true during the 12 months before and 18 months after Peak Height Velocity (PHV) occurs. On average, females experience this growth spurt from 11-14 years of age, while males are typically 13-16 years old. Therefore, all athletes are likely to enter the window of trainability for MAS during the T2T stage. In contrast, most females and few males will enter the window of trainability for strength during T2T. However, it is essential that the progression to more intense training is governed by each athlete's individual growth. Great care must be taken during the growth spurt to avoid inappropriate loading of under-developed muscles and energy systems.

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In the L2T Dryland RM, you were introduced to some basic facts about the aerobic and anaerobic processes that create energy in the human body. Those facts are outlined in the table below

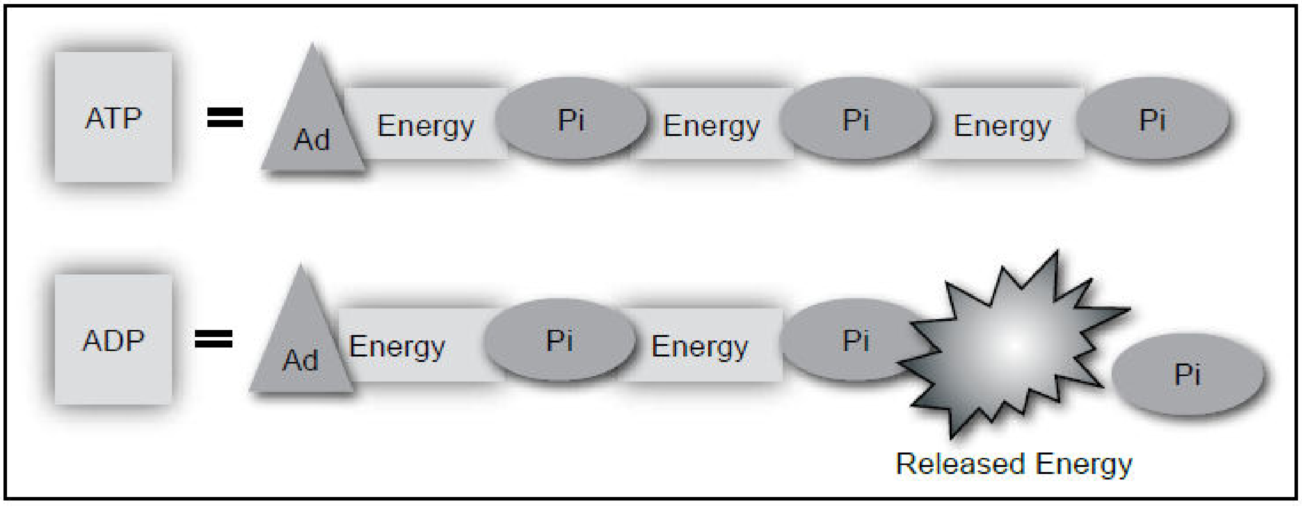
Anaerobic Processes	Aerobic Processes
❑ High power (immediate response)	❑ Low power (1-3 min. delay)
❑ Low capacity (60-90 sec.)	❑ High capacity (several hrs.)
❑ Predominate in Type II (fast) muscle fibres	❑ Predominate in Type I (slow) muscle fibres

The T2T Dryland RM expands on these basics. The information below is designed to give you a detailed understanding of the metabolic systems that provide the energy for movement. Understanding the time frames within which each system can operate and the length of time required for each to recover are vital to identifying the types of activities that will develop these systems and to designing developmentally appropriate training sessions. This reference material also describes the specific types of training that should be prioritized, as well as training to be avoided.

4.1.1 Introduction to ATP Metabolism

ATP (adenosine triphosphate) is the body's special carrier for free energy. Figure 4.2 below shows you how energy is stored in phosphate bonds and released when those bonds are broken. Anywhere that work is done in the body, the phosphate bonds in ATP are broken down to yield energy, which results in carriers called adenosine diphosphate (ADP) and sometimes adenosine monophosphate (AMP) because they have fewer phosphate bonds. Each item refers to the number of remaining phosphate bonds in the molecule (e.g. di = two, mono = one).

Figure 4.2: How Energy Is Stored and Released (adapted from Baechle and Earle, 2000)



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- ATP is the body's storage unit for free energy.
- Energy is stored in phosphate bonds and released when those bonds are broken.

The metabolic systems of the human body are designed to take fuel and convert it into ATP so that stored energy is always available when needed. Since the body's capacity to store ATP is limited, some fuel sources are stored in various parts of the body so that they can be mobilized and converted to ATP when energy demands increase. Fat and glycogen are prime examples of stored fuel sources that can be mobilized into the blood stream and delivered to any location in the body where energy demand is high. During exercise, the muscles are primary destinations for these fuel reserves. Once they arrive at the muscle, fuels go through a series of ATP- generating reactions, which have been referred to as the aerobic and anaerobic processes. The ATP generated by these processes is then broken down to perform work.

4.1.2 Anaerobic Energy Systems

The anaerobic processes consist of two types of energy pathways. Each pathway is composed of different energy releasing reactions, which simultaneously release waste products that inhibit muscle contraction when they accumulate in large enough amounts. However, the anaerobic reactions can be reversed in the presence of adequate fuel and/or oxygen. Therefore, when aerobic processes are not operating at their maximum rate, anaerobic waste products can be cleared from the working muscles and the body's most basic method of energy storage (phosphate bonds) can be replenished. This rate of replenishment increases as overall energy expenditure decreases (e.g. slowing down from running to walking).

- **Alactic Energy System.** One type of anaerobic energy pathway is called "alactic" because these reactions release energy without producing lactic acid in the process. These pathways are activated immediately when energy demands increase but they have a very limited capacity because they rely solely on phosphate stored inside the muscle. Figure 4.3 below illustrates that phosphate is stored in two ways inside the muscle. ATP and phosphocreatine (PC) can both release their phosphate bonds but energy for muscle contraction comes from ATP only.

  Therefore, when PC is broken down, the free phosphate can be used to reform ATP from ADP - and then the breakdown of ATP can continue to provide very rapid energy. As a result of limited PC stores in the muscle, the alactic system can only supply energy for the first 10 to 15 seconds of a maximal effort.

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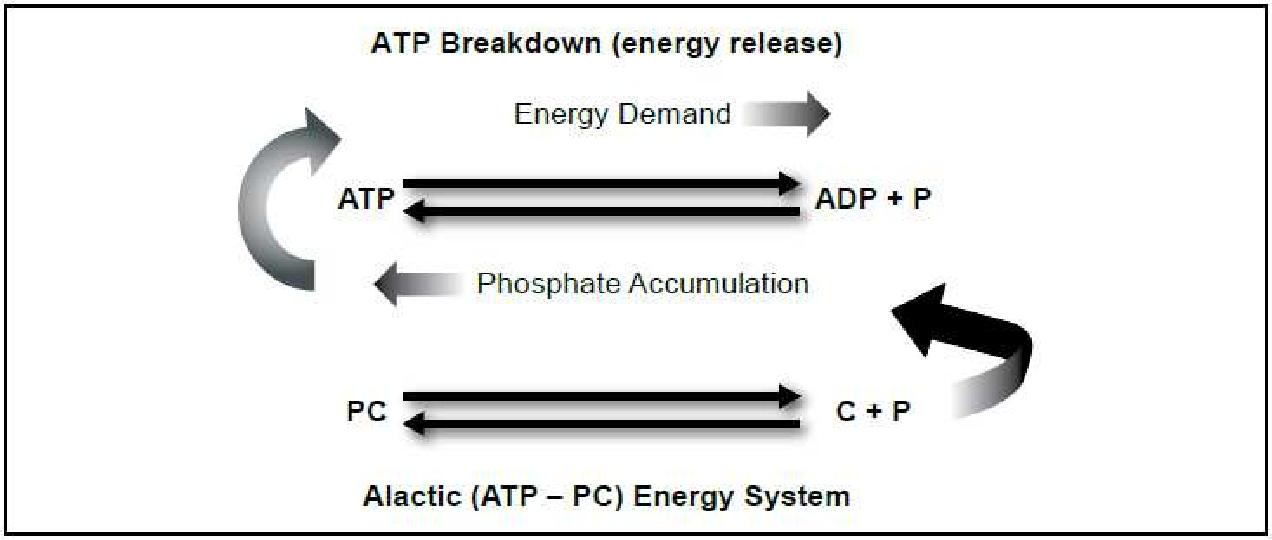
Figure 4.3: Phosphate Stored Inside Muscle (adapted from Norris and Ellis, 2001)



- ✓ Very small amounts of ATP are stored in all tissue (about enough to do one or two seconds of work in a muscle fiber).
- ✓ Phosphocreatine (PC) can be broken down into creatine (C) and phosphate (P). When PC is broken down, the resulting P accumulation creates a gradient that favors ATP resynthesis via the combination of P and ADP.
- ✓ The process of transferring P from PC to ATP can be thought of as “recycling” ADP; there are enough phosphates stored in the muscle as PC to account for 10-12 seconds of additional work by ADP recycling.

- ❑ **Lactic Energy System.** The other type of anaerobic energy pathway is called the “lactic” system. It consists of a series of ATP producing reactions, called “fast glycolysis”, which use glucose (sugar) as a fuel source and produce an end product called pyruvic acid. Figure 4.4 below illustrates this process. In the presence of oxygen, pyruvic acid will be used to create more ATP via aerobic processes (refer to Figure 4.5). However the breakdown of glucose to pyruvic acid can proceed so rapidly that there isn’t enough oxygen present to allow all the pyruvic acid being generated to enter the aerobic system. When this happens the excess pyruvic acid is converted to lactic acid, which will accumulate in the muscle until adequate oxygen is available to reverse the reaction or clear the waste products.

  Due to the harmful effects of acidic waste products on muscle function and the limited amount of glucose stored in the muscle, the lactic system can only supply energy for 60 to 90 seconds when it is operating at its maximum rate. After that, the muscle cannot function until some of the acid has been removed via the aerobic processes or in the blood stream. The lactic energy system can continue functioning at a submaximal rate for much longer periods of time as long as glucose stored outside the muscle (eg. in the liver) is mobilized and delivered to the contracting muscles. However, this process takes time and requires additional ATP so it is only possible when the intensity of the exercise can be maintained for longer than 90 seconds.

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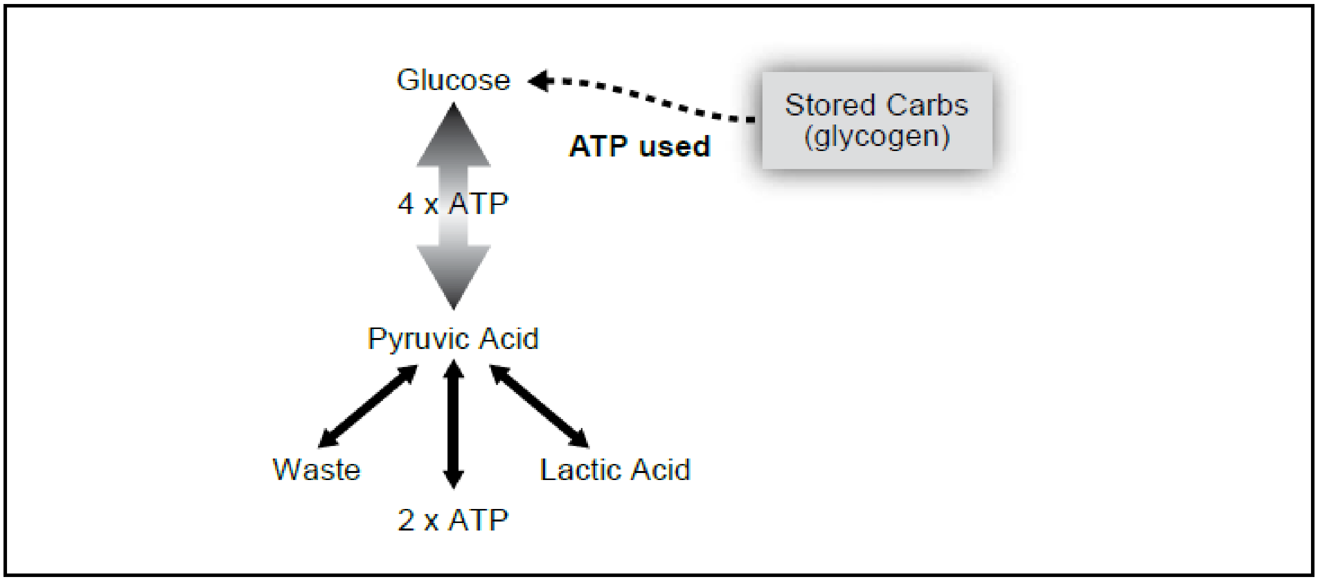
Figure 4.4: Lactic Energy System (Fast Glycolysis)



- ✓ Glycolytic reactions are reversible when energy demand is decreased.
- ✓ Mobilizing stored glucose takes time and energy.

4.1.3 Aerobic Energy Systems

- ❑ **Aerobic Energy from Glucose.** Before being used for aerobic energy production, glucose must be broken down to pyruvate. This process is referred to as "slow glycolysis" because pyruvic acid must interact with oxygen in order to create pyruvate, which is a slower process than converting pyruvic acid to lactic acid as in "fast glycolysis". Once pyruvate has been formed it can be transformed to acetyl Co-A, which enters a series of reactions that generate many ATP molecules. This series of reactions is cyclic so it does not need to be reversed during recovery.

  ATP can be generated in the same manner regardless of the energy demand but it is a much slower process because there are so many steps involved. For this reason, there is sometimes more glucose available than the aerobic system can process. In this case, the excess pyruvic acid will be converted to ATP via the lactic system (see Figure 4.4). Figure 4.5 demonstrates how ATP can be generated via aerobic processes.

- ❑ **Aerobic Energy from Fat.** Stored fat can be broken down into triglycerides, which can also be transformed to acetyl Co-A and enter the cycle of ATP generating reactions. This is also illustrated in Figure 4.5. The process of mobilizing stored fat, breaking it down to triglycerides, and transporting it to the active site via the blood stream is time consuming and requires ATP to be used. Therefore, this form of ATP production doesn't make a significant contribution when energy demand is very high. However, when energy demand is low enough that time and ATP are adequate for triglyceride mobilization, fat stores provide the most efficient source of aerobic energy because one gram of fat can be converted into more energy than one gram of carbohydrate or protein.

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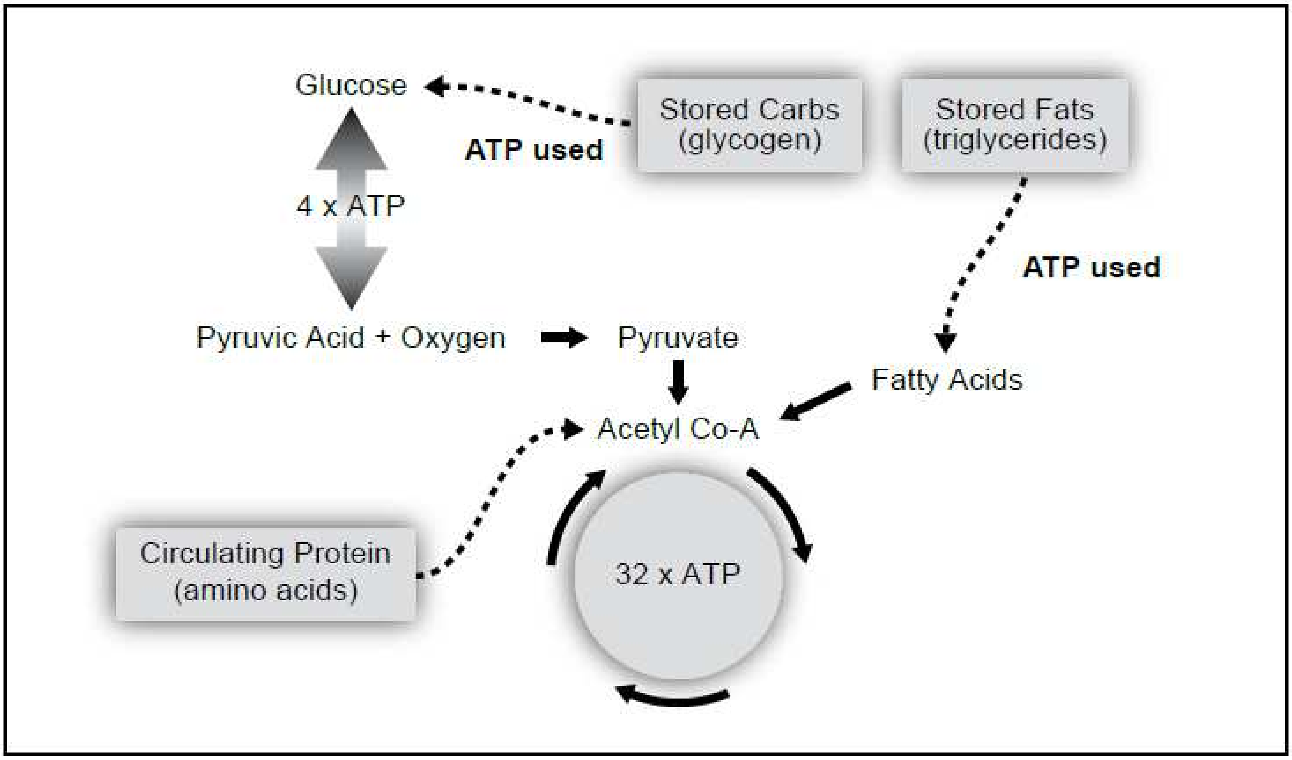
One reason why long slow workouts are so important to endurance athletes is that they help train the body to use its most efficient forms of energy production. But in order for fat stores to be used as an energy source, aerobic energy must be simultaneously generated from stored glucose. It is therefore very important that endurance athletes keep their glucose stores high by eating a diet rich in carbohydrates.

Figure 4.5: How ATP Is Generated



- **Aerobic Energy from Protein.** When energy demand is maximal and energy sources are depleted the body can use amino acids (from protein) as a source of acetyl Co-A. This is also illustrated in Figure 4.5. However, amino acids are the building blocks for all the body's tissues (including muscle fibers) so they are not a desirable energy source and, therefore, do not make a significant contribution to ATP production during normal exercise. The use of amino acids as a significant energy source means that the body is in a state of breakdown and exhaustion is imminent. While this will happen during very intense exercise, it is unsustainable and should be thought of as the body's emergency response system to maximal energy demands. The need to replenish the lost amino acids is why many high performance athletes have a "recovery drink" immediately following very intense training or racing.

In Summary

The aerobic energy systems begin with glycolysis, but pyruvic acid is converted to pyruvate using oxygen (slow glycolysis) rather than being converted to lactic acid (fast glycolysis).

Once created, pyruvate enters a cycle where many ATP can be generated by direct

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transformation as well as by adding triglycerides (from stored fat) and sometimes amino acids (from the body's pool of circulating building blocks).

Once ATP has been generated, it can be transported to the exact location within the cell where work needs to be done (e.g. muscle fibers). Once it has arrived at the target site, ATP can be broken down for energy release.

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4.2 Training Intensities Overview

During the T2T stage of development, both male and female athletes begin their growth spurt. The increases in heart, lung and muscle size that accompany this growth have a profound impact on the physical capabilities of these athletes. In addition, maturation begins to affect the physiological functioning of athletes' bodies during exercise. A bigger heart and lungs result in increased aerobic power, and anaerobic processes begin to mature as an athlete approaches Peak Height Velocity (PHV). This physiological maturation continues once PHV is achieved.

Although T2T athletes are becoming taller & stronger, it is important to respect the increased stresses (physical & emotional) and energy demands that rapid growth causes. Therefore, an athlete's training needs begin to be more specific but a conservative approach to training their maturing anaerobic processes is essential. This is reflected in the training intensities used. Advanced lactic training is inappropriate for T2T athletes so there is no LAC intensity zone at this stage.

Figure 4.6 illustrates the evolution of training intensities from the L2T through the T2W stages of development. It demonstrates that the specificity of the training targets increases as athletes mature physically and gain training experience.

Figure 4.6: Increased Specificity of Training Intensities from L2T to T2W

<table>
<tr><th>L2T</th><th>T2T</th><th>L2C</th><th>T2W</th><th>Primary Energy Source (Sust. time at Steady Pace)</th></tr>
<tr><td rowspan="4">Endurance</td><td rowspan="4">Endurance</td><td rowspan="2">End</td><td>Easy</td><td>Aerobic - fat (>180′)</td></tr>
<tr><td>Sub</td><td>Aerobic –fat + glucose (120′ – 300′)</td></tr>
<tr><td>AeT</td><td>AeT</td><td>Aerobic – aerobic glucose + fat (90′ – 180′)</td></tr>
<tr><td>Trans</td><td>Trans</td><td>Aerobic – glucose (75′ – 120′)</td></tr>
<tr><td rowspan="4">Intensity</td><td>AnT</td><td>AnT</td><td rowspan="2">AnT</td><td>Aerobic –glucose + Lactic (AnT) (20′ – 60′)</td></tr>
<tr><td rowspan="3">Race</td><td rowspan="2">Race</td><td>Lactic + Aerobic – glucose MLSS B (15′ – 30′)</td></tr>
<tr><td>CS</td><td>Lactic + Aerobic CS (6′ – 14′)</td></tr>
<tr><td>MAS</td><td>MAS</td><td>Lactic + Aerobic VO max (MAS) (2.5′ – 5′)</td></tr>
<tr><td rowspan="5">Sprinting</td><td rowspan="3">MAS
(LAC training inappropriate)</td><td rowspan="3">LAC</td><td rowspan="3">LAC</td><td>Lactic + Aerobic (1.5' – 2') –Advanced Lactic Capacity</td></tr>
<tr><td>Lactic (45" – 70") – Lactic Capacity</td></tr>
<tr><td>Lactic + Alactic (30" – 45") – Advanced Lactic Power</td></tr>
<tr><td rowspan="2">Sprint</td><td>Sprint</td><td>Sprint</td><td>Alactic + Lactic (10" – 20") – Lactic Power</td></tr>
<tr><td>Speed</td><td>Speed</td><td>Alactic (2" – 8") - Alactic</td></tr>
</table>

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4.2.1 Training Zones for T2T

Training intensities for the T2T stage of development are described below. Once again it is important to note that the continuum of all training intensities can be grouped or classified in many different ways. The five “training zones” described below are intended to provide adequate training specificity while respecting the developmental limitations of the anaerobic and aerobic energy systems in T2T athletes. The heart rate and blood lactate examples associated with each zone are specific to athletes who are growing rapidly and approaching or experiencing puberty. For athletes that have not begun the rapid acceleration phase of their growth, the three training zones described in section 4.1 of the NCCP L2T (Dryland) Reference Material will be more appropriate for categorizing activities. To review the developmental milestones expected during the L2T and T2T stages of development, refer to section 2 of this Reference Material.

- **Endurance Training.** This intensity was introduced in the L2T stage of development and remains unchanged. Training at this intensity helps to develop the central cardiovascular mechanisms that deliver oxygen to the muscles. As the athlete matures and “long” workouts are lengthened slightly, training at this intensity also helps the muscles to maintain their efficiency at using the oxygen that is delivered. Athletes in the T2T stage of development typically perform “endurance training” at 60-80% of HR_{max} or lower. Blood lactate values do not exceed 1.0 mM. Zone 2 training is included in this training category for technique purposes, as athletes at this stage of development will have to push into zone 2 (1.5 to 2mmol lactate) to maintain good technique during workouts. As long as the time spent in zone 2 is limited during the workout, athletes can creep into this training zone in order to maintain technique.

- **Anaerobic Threshold Intensity Training.** Training at this intensity improves the muscles’ ability to function efficiently in an acidic environment, and also improves their ability to clear lactate and use it as an energy source. As an athlete completes the major growth spurt (post-PHV), the lactic system begins to develop more completely and the capacity to clear lactate improves. For girls, this may happen mid-way through the T2T stage. For boys, it is more likely to occur at the end of T2T or even in the L2C stage of development. Targeted anaerobic threshold training is not a priority during the T2T stage but as athletes mature the amount of anaerobic work they do when their heart rate is greater than or equal to 85% of its maximum will naturally increase after PHV has been achieved. Although there are individual differences, anaerobic threshold generally corresponds to about 85% of HR_{max} in T2T athletes. Due to the fact that the anaerobic metabolism does not begin to mature until after PHV, blood lactate values are typically about 2.5 mM.

- **Race Intensity.** This range of intensities develops specific endurance by improving the efficiency of the exercising muscle. Efficiency improves for two major reasons. First, the muscle fibers get better at extracting oxygen from the blood at higher intensities. Second, the muscle groups become better coordinated as they “practice” working together at higher contraction rates to produce more force. While most racing will occur at this intensity, this type of training is not systematically introduced into the training environment until after PHV has been achieved. It should be a lower priority than other intensity training (Anaerobic Threshold, Maximum Aerobic Speed)

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- **Maximum Aerobic Speed.** This intensity develops an athlete's maximum ability to use oxygen to produce energy (VO_2max). VO max improves the most by training at this intensity. It is an appropriate training intensity throughout T2T, should be a higher priority than anaerobic threshold training, but overemphasis and/or inadequate recovery will be detrimental to training adaptation and the maintenance of good technique. Athletes in the T2T stage of development often achieve 90-100% of HR_{max} during race intensity exercise. However, unless the effort exceeds race intensity and becomes a lactic sprinting effort, blood lactate values rarely exceed 4.5 to 5 mM before PHV has been achieved.

- **Sprinting.** During T2T, the primary goal of sprint training is to improve muscular power and coordination. Prior to PHV, sprinting doesn't produce significant amounts of lactate because the anaerobic metabolism is not mature enough. During the growth spurt, which typically lasts 2 years, the anaerobic energy systems mature but can be very easily overloaded by sprinting efforts lasting longer than 15 seconds. Therefore, sprint training efforts during T2T should last less than 15 seconds and should allow enough recovery between repetitions to keep lactate below 2.5 mM at all times during the workout. The focus should be on developing excellent technique at maximal power outputs so that peak acceleration can eventually be reached by the end of the repetition.

- **Pure Speed.** Efforts in this intensity zone should focus on performing perfect technique while moving as fast as possible. These efforts last 2-8 seconds and require lots of rest between repetitions (eg. 5 – 7 minutes of very easy effort or complete rest) so that the quality of each repetition is maximized. Although the level of effort for Sprinting and Pure Speed are identical, two distinct training zones have been created to emphasize the importance of developing speed of limb movement as well as the overall technique and coordination required for faster ground speed in various race specific situations.

4.2.2 Training Targets: Relating RPE, Heart Rate and Blood Lactate to the T2T Training Zones

As mentioned at the beginning of this section, cardiovascular maturation begins during the T2T stage of development. As the heart and lungs grow and muscle mass increases, the anaerobic metabolism begins to mature. As well, the power and capacity of the aerobic metabolism increase. This global maturation changes the way the body responds to exercise and necessitates increased specificity of training intensity targets compared to what was appropriate for athletes in the L2T stage of development. Figure 4.7 summarizes the Ratings of Perceived Exertion (RPE), HR ranges and approximate blood lactate concentrations (BLa) that correspond to each of the training zones described above for athletes in the T2T stage of development. In addition, Figure 4.8 illustrates how the physical changes that occur during the transition from L2T to T2T stages of development affect the relationship between RPE and training intensity. There are several important points to note in these figures.

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Figure 4.7: Approximate BLa, RPE, Speed and HR Targets for T2T Athletes

T2T Training Zone (for YTP)	T2T Training Zone (detailed)	HR Range (% HRmax)*	% of MAS	RPE Range (Borg Scale)	Blood Lactate[1]
ZONE 1-2	**Endurance**	~ 60 – 80%	50-75%	7 – 12	1.0
ZONE 3	**Anaerobic Threshold (AnT)**	~ 80 – 90%	~80-85%	13 – 15	~ 2.5
ZONE 4	**Race pace**	~ 85 – 95%	~85-95%	15 – 17	~ 4.5
	Maximal Aerobic Speed (MAS)	95 – 100%	100%	17 – 19	~ 5.0 - 8.0
SPRINT	**Sprinting**	N/A	~110-130%	20	<2.5
SPEED	**Pure Speed**	N/A	~130%	20	N/A

Compared to L2T training targets, you will notice that higher RPE values are possible in the T2T "endurance" and "race intensity" zones. Research shows that younger athletes tend to rate their effort slightly lower than more mature athletes. Although all of the reasons for this are not clear, there are several physical developments that help explain this observation. One important factor is that maturing athletes improve their ability to sustain any given level of effort for longer periods of time, which can increase the perceived difficulty of the effort. As neural and technical developments are consolidated, ski speed and power increase, resulting in the athlete's ability to sustain harder efforts for longer time periods and to achieve faster top speeds.

In addition, efforts in the "race" and "lactic sprinting" zones are accomplished with an increasing contribution from anaerobic metabolism because the muscular and anaerobic systems develop throughout the T2T stage. As this maturation occurs, the accumulation of acidic waste products also increases, potentially resulting in an increased perception of effort during race type efforts.

Figure 4.8 provides general guidelines for typical RPE values corresponding to each training zone in the L2T and T2T stages of development. You'll notice that the RPE ranges in Figure 4.7 are a bit wider than those shown in Figure 4.8 for T2T athletes. This is to account for individual differences in perceived exertion, as well as further maturational changes that can occur during T2T as athletes complete their growth and move into young adulthood.

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Figure 4.8: Relationship of RPE to Intensity in Maturing Athletes

<table>
<tr><th>L2T Training Zones</th><th>Rating of Perceived Exertion (RPE)</th><th>T2T Training Zones</th></tr>
<tr><td></td><td>6 No exertion at all</td><td></td></tr>
<tr><td rowspan="6">Endurance</td><td>7 Extremely light</td><td rowspan="5">Endurance</td></tr>
<tr><td>8</td></tr>
<tr><td>9 Very light</td></tr>
<tr><td>10</td></tr>
<tr><td>11 Light</td></tr>
<tr><td>12</td><td rowspan="2">Anaerobic Threshold (AnT)</td></tr>
<tr><td rowspan="4">Intensity</td><td>13 Somewhat hard</td></tr>
<tr><td>14</td><td rowspan="4">Race Intensity</td></tr>
<tr><td>15 Hard (heavy)</td></tr>
<tr><td>16</td></tr>
<tr><td rowspan="4">Sprinting</td><td>17 Very hard</td></tr>
<tr><td>18</td><td rowspan="2">Maximum Aerobic Speed (MAS)</td></tr>
<tr><td>19 Extremely hard</td></tr>
<tr><td>20 Maximal exertion</td><td>Sprinting & Speed</td></tr>
</table>

The combination of metabolic maturation with growth in the heart, lungs and muscles also results in important changes in the relationship of heart rates to training intensity. Generally speaking, as an athlete's anaerobic system develops, more anaerobic work will be done at approximately 85% of maximum heart rate. This is addressed through the addition of an "anaerobic threshold" training zone at the T2T stage (see Figure 4.7).

An athlete with L2T maturity will still be doing aerobic work at 80-85% HR_{max} but an athlete with T2T maturity (typically in Phase 3 of the growth curve, as illustrated in Figure 23 of section 2 in this Reference Material) will be engaging more anaerobic processes at 85% HR_{max}. For this reason, it is recommended that T2T training intensities be prescribed using %MAS rather than % HR_{max}. Target HR's can be calculated using the Karvonen method, which takes the athlete's resting HR and maximum HR (both of which will change during T2T) into account when calculating exercise intensity.

In addition, as anaerobic machinery matures and ski technique becomes more efficient, anaerobic endurance will improve. This allows athletes in the T2T stage of development to develop a wider range of ski speeds at race intensities and gradually improve their ability to sustain 90-100% HR_{max}. It is essential, however, to understand that during the T2T stage of development, time trials and racing are the only appropriate means of "training" the ability to sustain these very intense efforts. The high muscle forces and

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cardiovascular loads that result from intensity of this kind place a great deal of strain on the muscular and skeletal systems. To prevent injury during the rapid growth that occurs in the T2T stage of development, these loads should not be imposed on a frequent basis.

Therefore, MAS training should consist of intervals lasting less than 90 seconds and should be performed at a pace that the athlete could sustain for much longer (up to 5 minutes). For example, during a workout of 8 x 30 seconds at MAS with 30 seconds rest, each interval would be performed at the same speed (covering the same distance) but the limited rest between intervals would make the pace progressively more difficult to maintain. The final 1 or 2 intervals would be perceived as almost maximal exertion (18-19 on RPE scale).

It is essential to understand that during the T2T stage of development, time trials and racing are the only appropriate means of “training” the ability to sustain efforts that elicit 95-100% HR_{max}.

Another important observation in Figure 4.7 is that the BLa values associated with the “AnT”, “race intensity” and “lactic sprinting” training zones may be lower than you expected. In adults, typical BLa values associated with AnT are around 4.0 mM and BLa values as high as 15 mM are often observed in adults performing repeated lactic sprinting efforts. However, the ability to produce and sustain these BLa values is the result of both physical and training maturity.

Although T2T athletes who are experiencing a growth spurt have begun to develop an increased muscle mass and are improving their ability to sustain more intense efforts for longer periods of time, they are still developing the physical characteristics necessary to allow the anaerobic processes to function in a mature manner. Once this physical maturation is complete, a number of years will be required for the anaerobic processes to be trained to maximum capacity and efficiency. Figure 4.9 illustrates the pronounced differences in BLa production that exist between immature and mature endurance athletes.

The graph in Figure 4.9 was generated by having two athletes complete a treadmill running test where they ran a slow initial speed (eight km/h and 11 km/h, respectively) for three minutes. At the end of three minutes, the athletes stopped briefly, a finger tip lactate sample was taken, the treadmill speed was increased by one km/h and the athletes ran at the new speed for another three minutes. This process was repeated until the athletes were near maximal effort. The curved lines are the result of plotting BLa against running speed for each stage of the test. The straight lines are the result of plotting average HR during the final 30 seconds of each three minute stage against each corresponding running speed.

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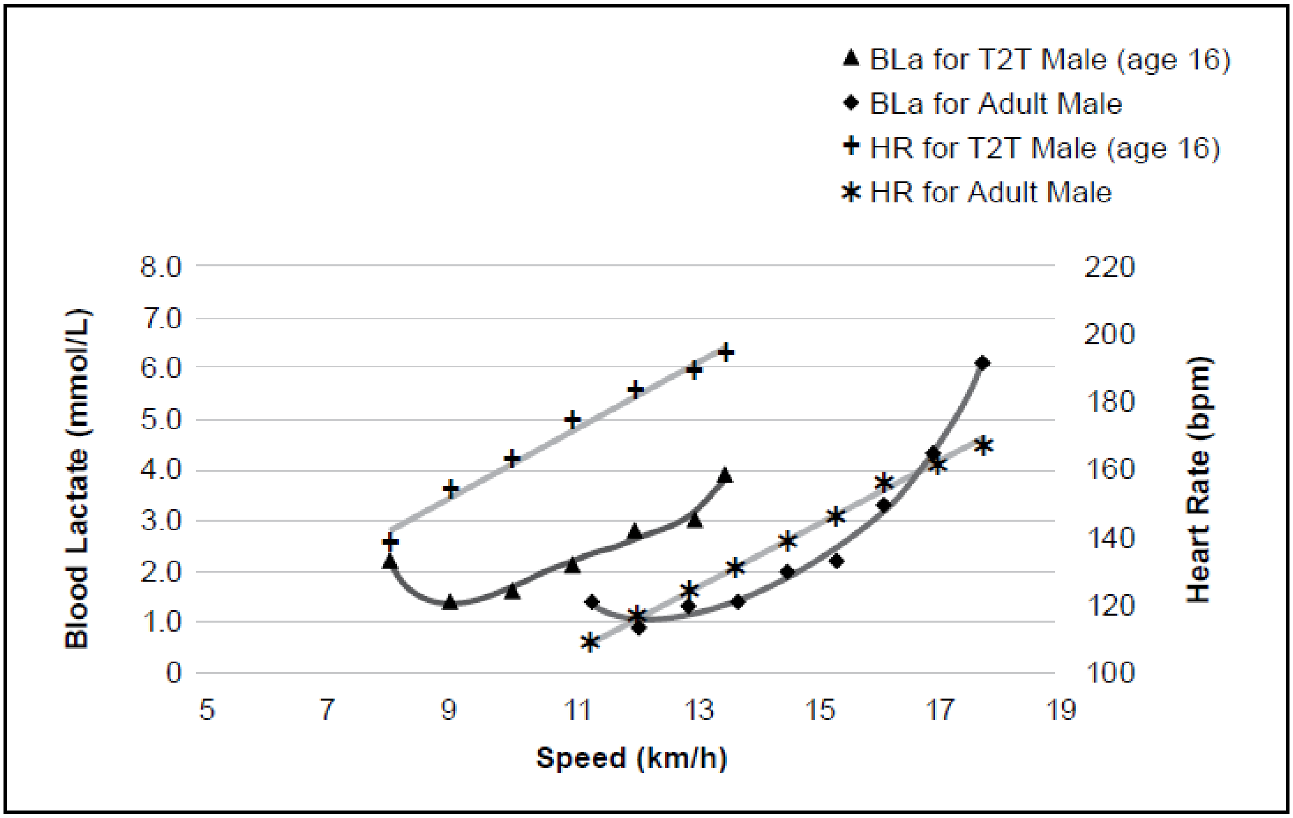
Figure 4.9: Developmental Differences in Blood Lactate Responses to Incremental Exercise



Both the shape and magnitude of the BLa curves demonstrate important differences in the capabilities of the anaerobic energy systems of these two athletes. The highly trained, mature adult male produces a smooth exponential curve, achieving a BLa value of approximately 6.0 mM at a HR of about 170 bpm (about 92% HR_{max} for this athlete). On the other hand, the T2T (age 16) male athlete experiences a basically linear increase in BLa from nine km/h to the end of the test, at which point he had achieved a BLa value slightly less than 4.0 mM at a HR of 200 bpm (about 98% HR_{max} for this athlete). The T2T athlete has produced far less lactate and come much closer to maximal exertion than the mature athlete.

The example in Figure 4.8 illustrates two very important points for the coaches of T2T athletes to remember.

- Targeted, systematic anaerobic threshold training is not recommended for T2T athletes because they do not have the physical capacity to produce much lactate at this intensity. Without the ability to create an acidic environment, it is impossible for these athletes to reap the benefits of training at this intensity. Instead, it is better for them to train and race for shorter periods of time at higher intensities with a focus on developing the technical ability to produce a wide range of ski speeds with excellent and sustainable execution.

- During the maturation process an athlete's lactate profile will change dramatically due to developmental factors such as increased muscle mass and maturation of anaerobic metabolism. Therefore, BLa testing is not recommended as a method of

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determining training zones. Performance-oriented assessment methods (i.e. standardized workouts or time trials) are recommended until the rapid deceleration phase of growth has ended. An explanation of these methods and their relationship to the T2T training zones is provided in Figure 4.10 and described in the following sections.

4.2.3 Pacing Targets: Relating Maximum Aerobic Speed (MAS) to the T2T Training Zones

As a coach of developing competitive athletes you are interested in how fast your young group can move in various race situations. You want them to be able to pace themselves in an individual start and to react to the attacks of their competitors in mass starts and sprint races. These are skills that T2T athletes can begin to learn in training as well as racing. In addition, knowing how fast your athletes can move when they are sprinting, using their VO_2 max, performing a distance race effort or going easy can help you to identify their natural strengths and address their weaknesses both physically and technically. One way of establishing the relationship between speed and different training intensities is to estimate the speed an athlete can achieve at VO_2 max and compare it to the speed at other intensities of effort (i.e. speed at AnT or during sprinting). The speed at VO_2 max is sometimes called maximum aerobic speed (MAS) and is defined as a steady paced running or ski speed that requires maximum oxygen consumption (VO_2 max) in order to be sustained.

With high performance athletes, MAS is measured using a treadmill (ski or running) and the indirect measurement of oxygen consumption ($V0_2$) via expired gas analysis. However, MAS can also be measured by more practical methods such as a time trial or an incremental treadmill run. In addition to providing valuable performance benchmarks by which a coach can measure progress, these field tests also give athletes several experiences essential to their development as competitive skiers. Most importantly, they are able to perform a maximum effort in a mildly competitive situation. By wearing a heart rate monitor, athletes can measure a maximum heart rate value and, in time trial situations, can also learn and improve the ability to maintain an even pace that results in the fastest possible finishing time without “blowing up” before the end or “having too much gas in the tank” in the finishing stretch.

Using a treadmill, MAS is estimated to be the fastest speed an athlete can attain during an incremental test similar to the one described in the previous section. An MAS test differs from the one used to generate a lactate curve in a couple of ways. Each stage of an MAS test is only one minute long and the speed is increased by one km/h each minute while the athlete continues to run. Finally, the athlete continues running until unable to keep up with the treadmill and forced to stop due to exhaustion. The fastest speed that was completed for a full minute is considered to be MAS. A heart rate monitor can be worn to record maximum heart rate at or near the end of the test. Of course, many coaches do not have access to a treadmill and do not find treadmill running speeds to be useful in setting ski training programs. In these cases, a time trial can be a much more practical and specific way of estimating MAS. If a time trial is used to estimate MAS it should last about five minutes and a HR monitor can still be worn to estimate maximum HR.

In a time trial, MAS is the average speed of the time trial (distance travelled divided by time

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to complete), provided that the terrain is relatively flat, the wind has negligible influence, and the effort is fairly evenly paced. Once MAS has been established, other training speeds usually fall within the ranges indicated in the third column of Figure 4.10.

Figure 4.10: Relating Training Zones to Maximum Aerobic Speed (MAS) and Exploring Speed vs Time Relationships

	T2T Stage		T2W Stage	
T2T Training Zones	**TTE***	**Training Speed**	**TTE***	**Training Speed**
Anaerobic Threshold (AnT)	20' - 30'	~80-90% MAS	45’ - 60’	78-82% MAS
Race pace	10' - 15'	~85-95% MAS	15’ - 20	85-88% MAS
Maximal Aerobic Speed (MAS)	2' - 5'	100% MAS	4’ - 6.5’	100% MAS
Sprinting	10’’ – 15’’	~110-130% MAS (as fast as possible)	8” – 15”	~140-160% (as fast as possible)
Pure Speed	2’’ – 10’’		2’’ – 8’’	

*TTE = Time to Exhaustion if an athlete moves at a constant speed until forced by fatigue to slow down or stop

Obviously, T2T athletes do not have as wide a range of training speeds as more mature and experienced athletes. Figure 4.10 illustrates the differences in % of MAS and TTE for T2T and T2W athletes at different intensities. This table demonstrates the marked differences between these groups that result from the maturity and years of training experience that T2W athletes possess. Compared to elite athletes, T2T athletes lack the aerobic and anaerobic power, as well as the technical prowess, to produce such a wide range of high end speeds.) The percentages of MAS indicated in Figure 4.9 demonstrate that the cardiovascular system (heart and lungs) and anaerobic metabolism of T2T athletes are not yet well enough developed to warrant the specific differentiation of training intensities used by elite athletes. This is reflected in the T2T training zones shown in the first column of the diagram.

4.2.4 Constructing Speed/Time Relationships

Although calculating all training speeds as a percentage of MAS obviously does not make sense for T2T athletes, the relationship between average speed and time to exhaustion

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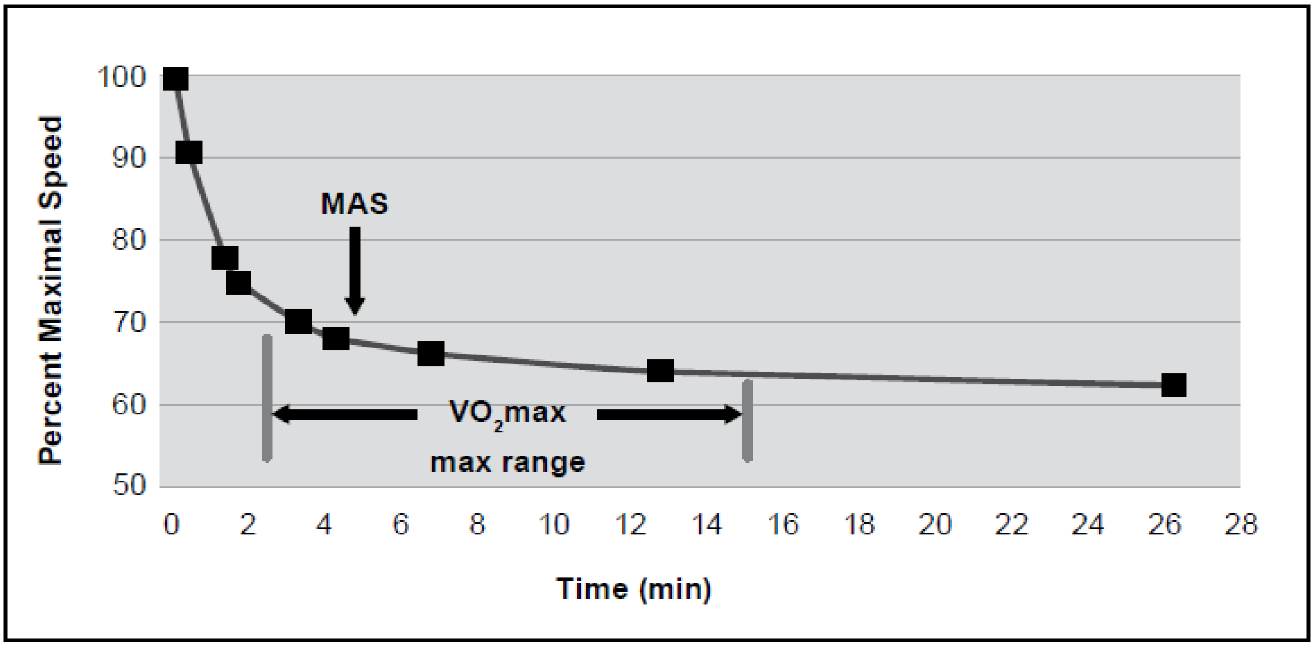
can be a valuable and practical way to make sure that your athletes are developing their technique and fitness across the full spectrum of movement speeds shown in Figure 4.10.

Plotting average speed versus time to completion (i.e. in a time trial) always results in a curvilinear relationship. Figure 4.11 illustrates this relationship for average running speeds in most adults. Note that each black square represents a separate time trial, with time to completion on the x axis and percentage of maximum speed on the y axis. In young athletes, there is often a smaller difference between maximum speed and MAS so the left side of the curve is not quite so steep. However, this is generally one of the first things to change with maturation and improved technical execution.

Figure 4.11: The Speed/Time Relationship for Adults (adapted from Hill, 1925)



Note that average speeds during tests lasting 2.5 to 15 minutes do not differ much compared to the changes observed from 0 to 2.5 minutes. This is because VO_2 max is the primary determinant of performance in all tests lasting from approximately 2.5 to 15 minutes. This time frame corresponds to race intensity in the T2T training zones.

Coaches wishing to construct speed/time relationships for their athletes can do so using the following three time trials.

- **Sprint Speed.** The average speed in a 60 m sprint.
- **MAS.** The average speed in a time trial lasting about five minutes; choose a distance or distances that will allow your group to finish in approximately five minutes. (A range of finishing times from 3.5 - 7 minutes will provide a relatively accurate estimate of MAS). Alternatively, a Leger test (Beep test) can also be used to obtain an estimate of MAS.
- **Race Pace.** The average speed in a time trial lasting 15-20 minutes (or whatever time frame is appropriate for a distance race effort); once again, distance may vary

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depending on the performance capabilities of your athletes.

Some important factors to consider when conducting these time trials are listed below:

- ❑ Pacing must be fairly even for the relationship between these three tests to be accurate.

- ❑ Environmental conditions (i.e. wind speed and direction, terrain, snow conditions – if skiing) must be consistent for the relationship between these three tests to be accurate.
  - ✓ Use a flat course with the least possible wind influence (loops are best).
  - ✓ Record the conditions on test days so that you have a reference point for comparison if you decide to repeat the test at a later date.
  - ✓ Try to have a “testing day” where all three tests are completed (i.e. 60 m sprint with MAS time trial immediately afterward and the race pace time trial two to four hours later; when this is not possible, perform the three tests as close together as you can.

- ❑ Check to see what percentage of the MAS is achieved during the race pace time trial. Is it more than 20% or less than 10% slower than MAS? Does this make sense based on the guidelines? (Note that it will take time for young athletes to learn the very important skill of pacing).

4.2.5 Using Speed/Time Relationships to Develop Training Priorities

Once you and your athletes have mastered the construction of speed/time relationships, you can track improvements over time in your selected measures. Figure 4.12 shows the upward movement of the curvilinear relationship as the full range of measured speeds increases. The left side of the curve shifts upward when sprint speed improves. Likewise, the right end of the curve moves up when endurance speed improves.

If an athlete has a very flat left side on his/her curve, you may wish to spend additional time working on technique and acceleration. This could be especially valuable if the speed/time relationship has been constructed for skiing. Similarly, if the difference between MAS and race pace is larger than the guidelines suggest, the athlete would benefit from a training program that focuses on improving endurance speed. It is also important to note that, due to the biological immaturity of both anaerobic and aerobic metabolisms, it will be very difficult to improve MAS through targeted training until after PHV has occurred. Therefore, for athletes in the T2T stage of development, the priorities for speed improvement should be as follows:

- ✓ **Priority 1.** Improve sprint speed (alactic sprinting).
- ✓ **Priority 2.** Improve endurance speed (endurance).
- ✓ **Priority 3.** Improve anaerobic endurance (MAS intensity).

As an athlete matures and develops better technical execution, the emphasis on

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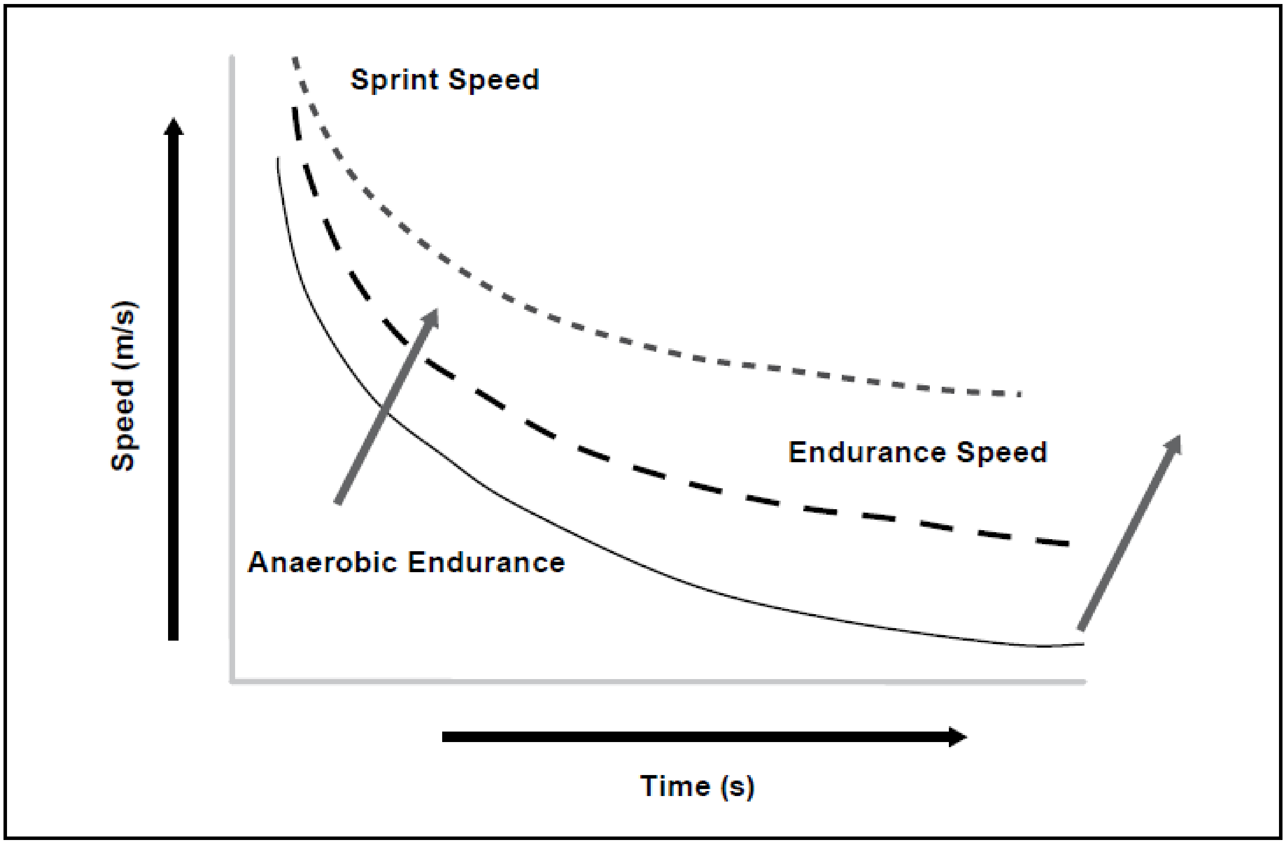
improving anaerobic endurance can gradually increase. However, the vast majority of the program should focus on improving the range of speeds that are included in the 'endurance" zone via improved fitness and technical abilities. It is also important to maintain the athlete's technical development by including small amounts of speed work on a regular basis. This approach will result in a well-rounded competitive athlete, ready to move on to the next developmental stage - Learning to Compete (L2C).

Figure 4.12: Improvement of the Speed/Time Relationship in Endurance Athletes (adapted from Norris and Ellis, 2001)



4.2.6 Testing T2T Athletes

While characterizing the performance capabilities of your athletes is an essential part of their development, it should be emphasized that the appropriateness of certain kinds of testing and specific training targets should be determined by the developmental stage of each individual. In addition, encouraging healthy growth and social development are the keystones of any club program. Therefore, particularly during the rapid and obvious changes that occur in T2T athletes, the main testing priority of T2T coaches should be monitoring growth and maturation (both physical and training maturity) on a regular basis.

Canadian Sport For Life and Cross-Country Canada have produced valuable resources to assist you in monitoring each athlete's growth curve and using this information to determine the most appropriate activities in which to engage. Keeping track of training hours, annual number and distance of races, and the development of "training skills" (i.e. understanding pacing, good nutritional practices, heart rate monitoring) will provide you with the most

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important markers of your athletes' success at this stage of development. In addition, developing these skills will help all T2T athletes enjoy cross-country skiing and other outdoor pursuits. This manual has been designed to provide you with the tools to address all of the testing priorities listed on the following page.

Testing Priorities for the T2T Stage of Development

1. Growth
2. Maturation
3. Training age (volume, races, "training skills")
4. Skill development
5. Speed
6. Fitness

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