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A Framework for Understanding the Training Process Leading to Elite Performance

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Contents

Abstract

The development of performance in competition is achieved through a training process that is designed to induce automation of motor skills and enhance structural and metabolic functions. Training also promotes self-confidence and a tolerance for higher training levels and competition. In general, there are two broad categories of athletes that perform at the highest level: (i) the genetically talented (the thoroughbred); and (ii) those with a highly developed work ethic (the workhorse) with a system of training guiding their effort. The dynamics of training involve the manipulation of the training load through the variables: intensity, duration and frequency. In addition, sport activities are a combination of strength, speed and endurance executed in a coordinated and efficient manner with the development of sport-specific characteristics. Short- and long-term planning (periodisation) requires alternating periods of training load with recovery for avoiding excessive fatigue that may lead to overtraining. Overtraining is long-lasting performance incompetence due to an imbalance of training load, competition, non-training stressors and recovery. Furthermore, annual plans are normally constructed in macro-, meso- and microcycles around the competitive phases with the objective of improving performance for a peak at a predetermined time. Finally, at competition time, optimal performance requires a healthy body, and integration of not only the physiological elements but also the psychological, technical and tactical components.

The limits of human performance are continually being pushed in keeping with the Olympic motto ‘stronger, higher, faster’. World-best sport performances appear to plateau for only short periods of time before being taken to new levels. This has been achieved by several factors including more sophisticated coaching, the year-round training of high-performance athletes in ‘amateur’ sports, better equipment, incentives that motivate athletes to push the boundaries of intensity and volume of training, and an advanced knowledge of training methodology. Another factor contributing to improved performances has been the participation of segments of the world population who were previously excluded. The purpose of this paper is to set out a comprehensive framework of the components of performance and training that should be addressed when developing a short- and long-term training plan leading to elite performance.

1. Components of Performance

In order to improve skill and performance in competition, athletes must prepare themselves through a training process where the physiological objective is to improve body function and optimise performance. The training process involves repetition of exercises designed to induce automation in the execution of a motor skill and develop structural and metabolic functions that lead to increased physical performance.[1] Thus, the goal of training is to increase the ability to sustain the highest power output or speed of movement for a given distance or time.[2] Within the training process, overcoming training and competition stresses promotes willpower, self-confidence and tolerance for higher training and competition demands.[3] Stress encompasses all aspects of training, competition and non-training factors.[4] Stress can have both positive and negative effects depending on the state of the athlete and recovery process. The ability to cope and manage stress determines the state of an athlete, which in turn determines the athlete’s reaction to subsequent stress.[5] During a training phase of several weeks or months, training load (defined by the intensity, duration and frequency of exercise) varies and should gradually increase in response to the training-induced adaptation of various physical systems. Overload training is the process of stressing an athlete at a higher level than previously tolerated in order to provide a stimulus for adaptation and supercompensation.[6,7] Supercompensation occurs when the overload training and the following recovery are balanced correctly and an overshoot in performance occurs.[8] In global terms, training represents the physical, technical, intellectual and psychological preparation of an athlete through physical and mental training.[9] The long-term goal of an athletic career should be sport mastery defined as consistent, successful, senior international competitive performance.

1.1 Factors Associated with Sport Performance

Over many years of organised systematic training, an athlete will develop work capacity, athletic shape and acquire sport skills, which with planned peaking, should result in a high level of performance. Work capacity or general fitness represents the foundation on which to base other training states,[10] whereas athletic shape refers to the ability to use the developed exercise capacity to execute a given sport activity under specified conditions.[11] Athletic shape is an extension of work capacity, and at a high level, an athlete may perform and attain results close to his/her maximum potential.[10] At competition time, physiological peaking is critical for optimal results and represents a point in time where fitness and fatigue differences are maximised in favour of the overall performance outcome.[12] With appropriate training and recovery techniques, fitness should be at a high functional state and fatigue reduced to minimal levels facilitating a high work capacity and quick recovery rate. Peaking for a competitive performance results in the highest level of athletic shape and is achieved through a tapering process. A taper is a period where training volume is reduced prior to competition[13] since residual fatigue may mask or attenuate fitness gains that have occurred through overload training.[14] Performance preparedness is the resultant of the interaction of the body's long-term fitness increase, stimulated by training, and the opposing short-term fatigue aftereffects of training.[11] It reflects the readiness of an athlete for either an enhanced level of training or to succeed in competition.[15] With tapering, fitness and skill should reach relatively high levels such that through physiological and psychological adaptations, the level of preparedness is optimised. Tapering is associated with physiological and psychological adaptations that have a positive impact on performance. Long-term training emphasis should produce definite improvement in a sports result unless the athlete's psychological platform or experience is insufficient to handle the pressure of competition. Sport reflects the state of development of physical and psychological pre-requisites of performance.[3]

Sport performance requires an athlete to integrate many factors (figure 1), some trainable (physiology, psychology and biomechanics), some teachable (tactics), and others outside the control of the athlete and coach (genetics and age). Other factors that play a role in performance include the competition environmental conditions, material and technical constraints, coordination, skill and the constitution of the mind and body.[3] It has been suggested that perhaps the major factor determining an athlete's potential to excel in his or her sport is genetic endowment, which includes not only anthropometric characteristics, inherited cardiovascular traits and muscle fibre-type proportions but also the capacity to improve with training.[16]

1.2 Genetics and Athletic Performance

When awe-inspiring athletic feats occur at international events, questions are often asked with reference to how an athlete or athletes could achieve such levels of performance. Was it simply a case of superior coaching, access to good facilities and beginning training at a young age or could their success be attributable to underlying biological predispositions?[18] Genetic traits are thought to account for up to half of the variation in performance between individuals and the other half in response to

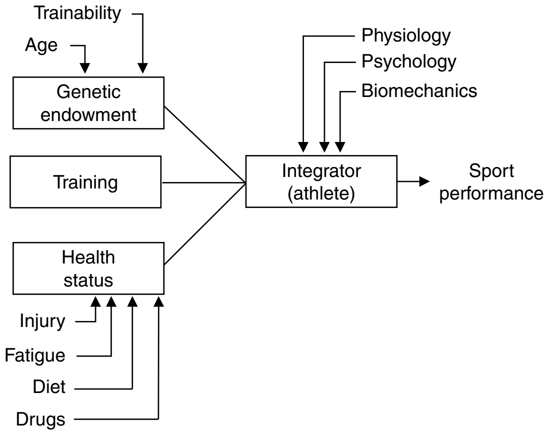

Fig. 1. Factors associated with sport performance (reproduced from MacDougall and Wenger,[17] with permission).

training.[19] The degree or magnitude of response to training may also be under the control of inherited traits, such that not only is the framework of the body regulated but that the plasticity of the response to environmental factors (i.e. training) is also under the same degree of genetic influence. The genetic potential of an athlete (genotype) is the combination of thousands of genes within the body forming its genetic constitution. Phenotype (anatomical, physiological and behavioural characteristics) is the observable constitution resulting from the interaction of its genotype with environmental influences. Genes have a large effect on muscle composition, height, length of the trunk, arms and legs.[20] However, functional factors such as the activity of enzymes in energy metabolism and cardiovascular endurance can be modified by different types and amounts of physical training.[21,22]

Some evidence examining the influence of genetic factors on human performance comes from research on the gene for angiotensin-converting enzyme (ACE) gene. ACE is responsible for the breakdown of vasodilator kinins while promoting formation of the vasoconstrictor angiotensin II (ANG II). ANG II, in turn, stimulates adrenal aldosterone release, leading to salt and water retention, thus influencing blood volume and pressure.[23] A polymorphism of the human ACE gene has been described in which the deletion (D allele) rather than insertion (I allele) is associated with higher activity by tissue ACE[24] and serum.[25] An allele is the expression of a gene in several forms usually arising through mutation. Humans carry two versions of the ACE allele[26] and different combinations of the two alleles results in three variants: II; ID; and DD. The frequencies of these three variants have been reported as 0.24, 0.50 and 0.26 for II, ID and DD genotypes, respectively, in a large cohort of healthy males.[27] Empirical evidence suggests that an I allele skew is associated with some aspect of endurance performance as excess frequency of the I allele in elite distance runners[23] and rowers[28-30] has been reported. Furthermore, mountaineers who have ascended beyond 7000m without supplemental oxygen demonstrate a significant excess of the I allele and II genotype (I allele and II genotype frequency 0.7 and 0.48, respectively).[31] To further complicate defining the type of endurance performance that is associated with an I allele (along a continuum from strength endurance to prolonged duration endurance), is the report that the duration of loaded repetitive biceps flexion increased in military recruits undergoing a 10-week physical training programme.[31] There was an 11-fold increase in the duration for II genotype compared with DD individuals suggesting that endurance of a relatively small muscle group may be influenced in an ACE genotype-dependent manner.[26]

Other studies, however, have failed to find an association or skew of the I allele and endurance athletes.[32,33] The most likely cause of these contradictory findings may be the selection of athletes from mixed sporting disciplines, therefore combining several different phenotypes.[26] However, the most compelling evidence for association of the I allele and endurance performance is the trend of increasing I allele frequency with distance run in Olympic standard runners (0.35, 0.53, 0.62 for <200m, 400–3000m and >5000m, respectively).[23] The benefit conferred by the I allele on endurance performance might involve genotype-dependent alterations in cardiorespiratory response to training.[34] Although maximal oxygen uptake ($\dot{V}O_{2max}$) is often used as a marker of aerobic fitness, endurance performance can vary greatly among athletes with equal $\dot{V}O_{2max}$,[35] and other factors such as running economy and speed at lactate threshold[36] influence submaximal endurance performance. Currently, there is conflicting evidence on the effect of training on $\dot{V}O_{2max}$,[37,38] whereas reduced oxygen consumption at a fixed exercise intensity (improved efficiency) has been reported.[34] This has lead to the conclusion that it is likely that local muscle effects, rather than a central cardiorespiratory mechanism, confer the enhanced endurance ability associated with the ACE I allele.[34,39] On the other hand, there is an accumulation of evidence that suggests that the D allele is associated with elite power-orientated athletic performance.[23,39] Myerson et al.[23] reported an increased frequency of the D allele among sprint runners (<200m) and a report on Russian athletes demonstrated an excess of the D allele in elite swimmers competing over short distances taking less than 1 minute.[40]

It will be of significant interest to identify the types of training that will result in optimal performance for those carrying a particular genotype since, with current training regimens, there are athletes who are superior, average, poor and non-responders to training.[21] Jones et al.[39] make the cautionary statement that the ACE I/D polymorphism should not be considered a 'gene for human performance', but a marker of modulation such that one would expect an excess of the I allele in the truly elite endurance athlete, with a concordant excess of the D allele represented in more power-oriented events. From the inherited trait perspective, whether a given person will be a champion appears to be associated with: (i) the actual state of a number of complex phenotypes before training; (ii) proper training, rest and nutrition; and (iii) the ability of the phenotypes to adapt to the training, rest and nutrition.[21] Skinner[21] remarks that it is probable that elite performers are those who begin with high levels of the characteristics (phenotypes) needed for success in their particular sport and also have superior adaptations in those characteristics after training. These comments may have some validity but the complexity of possible permutations of contributory factors may still not allow for accuracy in performance prediction.

1.3 Deliberate Practice and Athletic Performance

Talent (genetic endowment) is both an appealing and a common-sense explanation of what underlies skill in sport and most coaches believe that differences in talent determine who will succeed.[41] Properties of talent that have been suggested are: (i) talent originates from genetically transmitted structures; (ii) trained coaches may see early indicators identifying the presence of talent; (iii) early indicators of talent provide a basis for predicting who is likely to excel; (iv) only a minority of children are talented; and (v) talents are relatively domain-specific.[42]

Alternatively, sport performance and expertise could be the result of hours spent in focused, effortful training, rather than the effect of innate, inheritable traits,[43] a position that has its roots in 'The Theory of Deliberate Practice' presented by Ericsson et al.[44] Deliberate practice is defined as any activity designed to improve current performance that is effortful and not inherently enjoyable. Their primary prediction suggests that the amount of time an individual is engaged in deliberate practice activities will be monotonically related to that individual's acquired performance.[44] Ericsson et al.[44] suggested that for the attainment of expertise, it was not simply training of any type, but the engagement in 'deliberate practice'. Deliberate practice is made up of activities done to develop required abilities that are not intrinsically motivating, require effort and attention and do not lead to immediate social or financial rewards. Central to the notion of deliberate practice is the assumption that a direct relationship exists between the number of hours of deliberate practice and the performance level achieved.[45-47] A substantial body of evidence also suggests that elite performances require around 10 years of practice to acquire the necessary skills and experience to perform at an international level;[47,48] the 10-year rule was first discussed by Simon and Chase.[49] Nine years appears to be a watershed in soccer and field hockey, after which significantly more personal investment of time and effort must be committed if one is likely to reach international or national skill level.[47]

A confounding factor in the identification of talent is the observed influence of physical maturity. The organisational structure of youth sport appears to bias the selection procedure away from skills in favour of physical size.[18] The birth months of skilled athletes in the sports of soccer,[50] ice-hockey,[51,52] baseball[53] and cricket[54] have consistently indicated that elite performers are more likely to be born in the first quartile of the selection year than the last quartile. It is apparent that what coaches perceive as early talent are the advantages afforded by early physical maturation.[18] Therefore, current performance or competitive outcome is used as the definitive criterion rather than utilising a multifaceted evaluation format during the development years. The relative age effect includes physical, cognitive, emotional and motivational factors.[55] Noakes,[56] however, suggests that early specialisation in endurance running is not of benefit and that a young aspiring athlete should wait until his/her body has matured sufficiently before engaging in intensive physical training. Despite the monotonic association between hours of deliberate practice and the performance level achieved, Helsen et al.[47] indicate that a theory of expertise based solely on deliberate practice is still questionable. It may be that those who are more ‘talented’ are more motivated and consequently practice more.[47] Furthermore, they note that much of the data would suggest that the most critical part of producing skilled athletes is to find individuals who are highly motivated and are likely to persist over the long duration required to produce an expert.

1.4 Other Performance Factors

Other factors impacting the achievement of high-level performance include trainability of the athlete, neuromuscular efficiency and biomechanics, recovery potential and psychological factors, which include the ability to tolerate pain and fatigue. Trainability refers to the potential for improvement and is influenced by genetics, age, prior training history and current fitness/skill status. Neuromuscular efficiency, which can be significantly influenced by training, refers to the skill with which an athlete executes a given movement and relates to how efficiently and intensively the athlete recruits muscle fibres in the appropriate muscle groups to produce a movement pattern accurately and powerfully.[11] Attainment of consistent high performance is not achieved without an athlete building a solid psychological platform. The psychological factors include motivation, aggression, focus, the aptitude to tolerate pain and sustain effort, attitudes towards winning and losing, the ability to cope with anxiety and stress, coach-ability, the competence to manage distractions and the capacity to relax.[11] Preparing an athlete for and achieving a high level of performance places great demands on the character and constitution of an athlete. Tenacity, conscientiousness, perseverance and readiness to perform are some qualities of character required to overcome barriers of training and competition.[3] Recovery, which is part of the training process, is necessary in order to reduce fatigue and to induce training adaptation following training overload. Rest-recovery can be defined on two levels: (i) in reference to the amount of time between exercise sessions on a daily or weekly basis; or (ii) in reference to the amount of time between longer cycles or periods of training.[57]

The term ‘regeneration’ is sometimes used to refer to training cycles or periods of extended rest-recovery within a long-term training plan.[57] Kellman and Kallus[58] have suggested that recovery encompasses active processes of re-establishing psychological and physiological resources so that the athlete may tax those resources again either in competition or training. Recovery depends on a reduction of, a change of, or a break from stress.[59] Furthermore, recovery should be closely matched with the type, intensity and duration of previous training phases[7] and how an athlete handles training psychologically since athletes have wide variances in the extent to which they can tolerate the physiological and emotional stress of training.[60]

1.5 Types of Athletes

Although training aids every aspiring athlete at any level, there appears to be two broad categories of athlete who perform at the highest performance level. It seems, on the one hand, there are the genetically talented, and on the other hand, those with a highly developed work ethic, with a system guiding their effort. From a physiological perspective, every athlete possesses capacities of speed and endurance. Pyne[61] has suggested that while the concepts of developing fitness and speed in isolation are understood by coaches, an integrated approach is preferred for more complete development of these factors. He has proposed four categories of athlete, using the analogy of horses:[61]

1. Wooden Horse – low fitness/low speed: athletes who are just commencing training or returning from illness or injury.
2. Bolter – low fitness/high speed: athletes who have natural speed and may not find it necessary to do the same volume of work as their team mates. This athlete may have short-term success, but long-term progress to elite competition may be limited.
3. Workhorse – high fitness/low speed: these athletes are training specialists who are extremely dedicated and consistent in their workouts. However, they struggle to lift the quality of their efforts when in a competitive situation. This may be due to excessive training loads, insufficient recovery or inadequate speed work.
4. Thoroughbred – high fitness/high speed: the athlete with a combination of developed fitness and natural speed is likely to have the greatest chance of success and improvement in the long term, when in association with skill and tactical awareness.

Some coaches would argue that although thoroughbreds are a necessary ingredient for a successful programme, workhorses are also important as training partners or to push the squad training envelope and pull the thoroughbred along with them during periods of training overload. By ensuring that appropriate training is provided to suit the requirements of each individual athlete, the chances of making a workhorse more like a thoroughbred are increased and with correct peaking, a workhorse may also be highly competitive.[61]

2. Long-Term Training Strategy

2.1 Long-Term Planning

Long-term training spans a period between 10–15 years of an athlete's competitive life and is divided into the phases not by age but by the degree of their advancing ability. The phases are: (i) basic training of fundamentals; (ii) in-depth specialisation and progress towards maximum personal performance power and capacity; and (iii) reaching an international level of competition.[1,10] Once an athlete has reached the fringe level of international performance, a further period of 6–8 years of competitive experience may be needed to achieve consistent world-class stature. Some authors have designed relatively detailed long-term training regimes that address these different developmental time frames.[10,62,63] Balyi[64] has suggested a terminology and long-term athlete participation structure revolving around the following 'seamless' chronological and developmental categories: FUNdamental; Train to Train; Train to Compete; and Train to Win. Within such a structure of a long-term plan is the deliberate inclusion of a comprehensive monitoring and testing system examining a broad spectrum of current and potential performance characteristics and psychological traits.[65] This will assist the coach to continually assess and thus discover the strongest and weakest link in the athlete's training.[10]

Although the highest personal international performance(s) is usually achieved during the final phase of an athlete's competitive career, a distinct characteristic of long-term plans is the inclusion of general athletic and multi-activity physical preparation. The chronological age of highest performance will vary between sports and depend on attained technical skill of the athlete, developed power, endurance capacity and experience. The majority of athletes are most successful after they have reached athletic maturation.[10] Athletes, particularly females, in sports such as gymnastics, figure skating, swimming and tennis may realise top-level performance in their late teens or early twenties, whereas athletes participating in rugby, soccer, volleyball, speed skating, distance running and cross-country skiing achieve success in their late twenties or early thirties. Thus, the concept of training age is important to consider when a long-term plan is developed.

The training strategy necessary to achieve a long-term positive progression in the age-performance exponential curve[66] should include the careful selection of competitive opportunities appropriate to the athlete's performance level (novice, junior, senior). Long-term periodisation progress should not be subordinated to short-term competitive events.[15] Once talent has been identified at a young age, there is a tendency to exploit an athlete with early specialisation and an over-ambitious competitive calendar. Training tends to focus on the outcome (winning) rather than the process (optimal training) and over-competing results in under-training.[67] This often produces successful junior champions but they do not progress to be competitive at a senior level due to burnout (see section 5).

2.2 Stages of Athletic Career

An athlete, whose performance progression is presented in figure 2, was initiated into competitive swimming at the age of 10 years (stage 1) and undertook in-depth specialisation from the age of 14 years (stage 2) that resulted in the attainment of national team status by age 17 years. Mastery and stabilisation of high performance (stage 3) produced Olympic medals in 1996 and 2000. A long-term plan should reflect an athlete's improvement rate, such as that presented in figure 2, with a natural progression that is much higher at the beginning and during the specialisation phase (stage 2) than stage 3.[10]

The plan should be based on the recruitment of young, keen athletes who may show different levels of ability. During stage 1, sport fundamentals should be established as well as general athletic ability. For a young prospective athlete and junior athlete, the initial and specialisation stages should be solidly based on multi-activity physical preparation.[10] Specialisation aims at achieving the highest performance in an adult on the basis of versatility which can be achieved through involvement in various sports or activities. Early specialisation can lead to a one-sided training of junior athletes in one particular event. Such youngsters are generally capable of achieving good results at a relatively early age, but often do not improve their performances as expected, when they become adults. General versatility gives the background for later specialisation in one event and the broader the base is, the higher the standard will be in one event.[3] Since very different maturation processes are at work during the teen years, training programmes for the developing athlete should reflect these events rather than be tempered versions of adult or senior programmes.[65] Furthermore, as an athlete progresses through stage 2, parent education, lifestyle awareness and flexible school programmes need to be addressed in order to accommodate the increasing demands and discipline required of training.

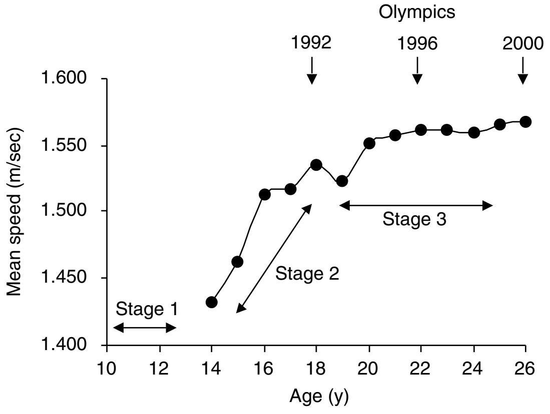

Fig. 2. Example of an age-performance exponential performance curve for a swimmer.

3. Variables and Components of Training

3.1 Intensity, Duration and Volume of Training

The dynamics of training involve the manipulation of the following training variables: intensity, duration and frequency. The intensity of training is a qualitative component and is a function of the activities performed in a given unit of time. Intensity measurement varies between sports. Where distance and time are factors, absolute intensity is recorded as speed. In activities performed against resistance, intensity is measured in kilograms lifted or thrown. In racket or team sports, absolute intensity may be measured by the frequency or pace of movement or the tempo of the game.[10] Relative intensity, on the other hand, can be quantified as a proportion of an athlete's maximum speed, race performance or a physiological variable such as maximum heart rate. For training prescription purposes, $\%\dot{V}O_{2max}$[68-70] or % heart rate reserve[71-73] are often used in research training studies or speeds based on ventilatory or blood lactate concentration parameters determined during an incremental progressive exercise test in a laboratory.[74,75] Ventilatory and metabolic parameters are superior to percentages of $\dot{V}O_{2max}$ for the determination of training intensity recommendations.[76] A study in endurance-trained individuals revealed intensities between 86% and 118% of the individual anaerobic threshold for a given 75% of $\dot{V}O_{2max}$.[77] This illustrates that the method used to determine training intensity has significant training implications, particularly when one considers the variance in training response of athletes supposedly undertaking an identical training programme.

Papers reviewing the influence of the three training variables on athlete adaptive response conclude that training intensity is the major parameter influencing the effects of training on the cardiorespiratory system.[78-80] Although high-intensity training has produced improvements in $\dot{V}O_{2max}$ in cross-country skiers,[81-83] cyclists[84,85] and distance runners,[86,87] improvements in performance have also occurred in trained athletes without any increase in $\dot{V}O_{2max}$.[84,88,89] It has also been shown that the addition of a small amount of high-intensity training to normal training can improve performance.[90] For a detailed review of high-intensity training see Laursen and Jenkins.[91] On a cautionary note, however, some authorities on this topic suggest that no more than 5–20% of the training load should be accomplished at intensities greater than the anaerobic threshold.[92-94] Although overtraining studies have failed to demonstrate impaired performance, there is a wealth of practical experience which suggests that a large volume of high-intensity training is poorly tolerated.[79]

Training frequency refers to the number of training sessions within a given time-frame such as a day or a week. It is common practice to have between 5 and 14 training sessions per week depending on the sport, the performance level of an athlete and the purpose of training at specific points in a training cycle. The duration of training is the quantitative component of training referring to the time or the amount of exercise in a training session. On the other hand, the volume of training implies the total quantity of training performed per week, month or year and is the combination of duration and frequency. The terms 'volume' and 'duration' are often confused and erroneously used interchangeably.[10,95] As an athlete progresses through the youth, junior and senior levels, and is able to tolerate the training load, the overall volume of training becomes important. A continual increase in training volume is probably one of the highest priorities in contemporary training, particularly for the aerobic sports.[10] In a study of cross-country skiers between the ages of 14 and 24 years, the average annual training distance for 1 week increased significantly in every age and sex group.[81] Similarly, training volume in marathon running has been shown to have a significant influence on performance outcome in recreational runners.[96-98] At the international level of endurance-based sports (e.g. cross-country skiing), it is common practice to accumulate between 800 and 1000 hours of training per year.[94] At the elite level of sport, the amount of volume increase is a function of the individual characteristics and specifics of a sport and a high correlation exists between volume of hours of training per year and desired performance.[10] As outlined in section 1.3, the monotonic relationship between the amount of deliberate practice and eventual performance outcome in the team sports of soccer and field-hockey[47] supports the notion of increased volume of training in the long term.

3.2 Training Load

Training load is a combination of the following elements: intensity, duration and frequency. Optimal training adaptation will take place if the magnitude of the training load is applied to a high-performance athlete in an appropriately sequenced manner. Coaches will often organise training both in the short- and long-term by alternating periods of increasing training load with recovery. Training loads can be classified as the loads of a single session or microcycle of 3–5 days in the following manner: excessive load (surpasses the functional capacity of the body and results in a form of overtraining); trainable load (results in a specific training effect); maintenance load (is sufficient to avoid a detraining effect); recovery load (favours promotion of the recovery process after a previous excessive or trainable load); and useless load (is below the intensity or value necessary to achieve any of the previously established effects).[1]

The determinants of the training load include: the specificity of training (amount of general versus specific training); training stimulus of the load; the magnitude of the training, which should be relative to the performance development status; the duration and intensity of cycles of training throughout a year; and the sequencing and interrelationship of the training elements in skill-dominated events.[11] The organisation of loading is closely associated with selecting the optimal rest between successive sessions. The rest pause is actually a training method which is just as important as muscular work, and it should be employed skilfully.[11] This highlights the extremely complex connection between an athlete's fitness state, training load and tolerance for training. However, it should be noted that the ability to sustain intensity (intensity endurance), whether it is of a short or long duration, is developed through the application of intensity. Furthermore, the typical description of training load erroneously focuses upon absolute demand rather than relative biological impact. Therefore, it is important that coaches and sport scientists quantify training load by attempting to estimate the actual effect on the athlete.

A method for objectively quantifying the training load, based on heart rate response, has been developed by Banister and associates.[99,100] The concept of training impulse (TRIMP) is determined as the product of training duration and intensity where the average heart rate is multiplied by a non-linear metabolic adjustment factor that is based on the classically described blood lactate curve and the duration of a training session.[99,100] This method of quantifying a training load can be used in the fitness-fatigue model of training response, which has been shown to account for variations in performance. A limitation of the TRIMP method, however, is that only aerobic training intensities, eliciting heart rate responses up to maximum heart rate, can be determined. Despite this drawback, this form of analytical and predictive training assessment deserves greater future attention and specific development examining the physiological impact of supra-$\dot{V}O_{2max}$ training intensities.

3.3 The S's of Training

For effective training, specific components of training must be addressed by a coach. Athletic performance incorporates the basic physiological components of strength, speed and stamina (endurance) in combination with skill. An athlete seeks to develop a fitness specific to the demands of the sport.[101] Exercises and sport activities are some combination of strength endurance, speed strength and speed endurance executed in a coordinated and efficient manner where training develops sport-specific characteristics (figure 3). The dominance of one of the basic components can be illustrated by weightlifting (strength), track sprinting (speed) and marathon running (endurance). Yet most sports require development of some combination of the specific components. Factoring into the training milieu is the potential negative effect of one training method on another component. Strength training for example has a profound negative influence on muscle mitochondria,[102] which are essential for endurance. Thus training is a complex process of mixing and sequencing the variables and components of training so that at competition time, a tapered athlete has maximised the physiological and skill components necessary for optimal performance.

Additional components are (p)sychology, suppleness, stature, and sustenance.[65,103] The psychological component has been discussed previously (see section 1.4). Suppleness or flexibility refers to the aspect of passive and dynamic actions, both specific and non-specific, where lack of flexibility may have negative effects on learning or executing techniques and impose extra workload and tension on those muscles compensating for the deficiency. Agility combined with flexibility results in mobility, which is the quality of performing a movement quickly with good timing and coordination through a wide range of movement, such as in diving, gymnastics, karate, wrestling and team sports.[10]

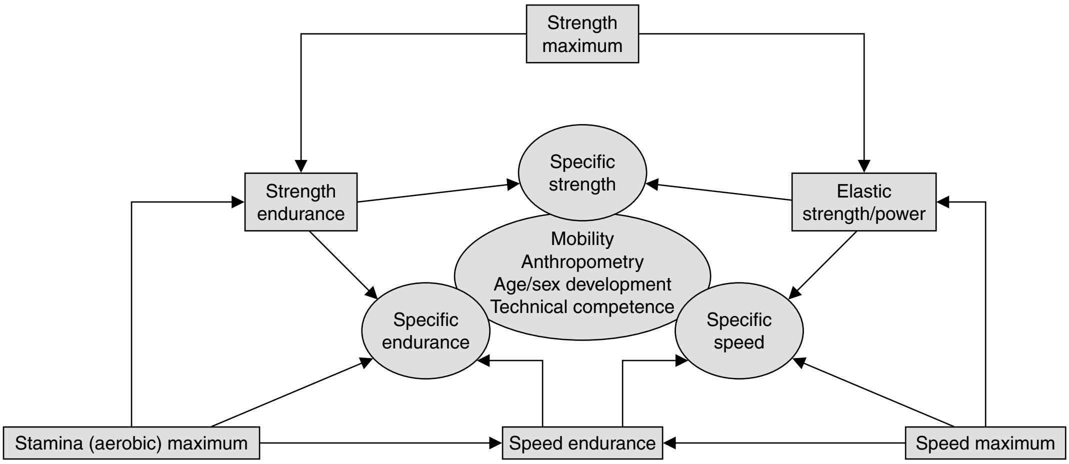

Fig. 3. Schematic representation of the relationship of basic fitness characteristics and their involvement in specific fitness required of individual discipline/sports (reproduced from Dick,[101] with permission).

Dick[101] uses the word 'mobility' to describe the capacity to perform joint actions through a wide range of movement where the influence of joint structure, elasticity of soft tissues and neuromuscular coordination are significant.

Stature and physique refers to those aspects of body development such as body mass, lean tissue mass and fat to muscle ratio, all of which are of interest in performance optimisation. In some instances, a particular morphological predisposition is an overriding factor in sport performance, e.g. height, or an average body build may be moulded to meet the demands of a sport.[104] A comprehensive anthropometric profile can be estimated from height, weight, skinfolds, girths, and skeletal length and breadth measurements.[104-106] Being meticulous, however, with accurate landmarking and measurement, is critical for reliable anthropometric measurements.[106] Current trends in body composition research include compartmental assessment using dual-energy x-ray absorptiometry (DEXA). The greatest advantage of DEXA over other laboratory methods may be the ability to assess regional as well as total body composition and analyse separate compartments of the body (fat, soft tissue and bone).[106] When the anthropometric status of athletes is measured routinely, loss of muscle mass or fat can be informative in assessing under-performance, and changes in segmental lengths and proportions may provide useful data in periods of rapid growth and development.[65]

The term 'sustenance' is focused on the need for sound nutritional practices and recovery strategies that aggressively counter the prior training or competition stress or at least aid the restorative process that a specific load has induced.[65] An adequate diet, in terms of quantity and quality, before, during and after training and competition will maximise performance. Rehydration and recovery of fluid balance after exercise,[107] together with the timing and method of increased carbohydrate intake to cope with heavy training, competition and recovery, are essential for optimal training.[108-110] Athletes are frequently undernourished with respect to carbohydrate, particularly in heavy training, therefore, their training and performance suffer.[111] Protein intake is also important, particularly during heavy training blocks. The daily protein intake of 1.2–1.6 g/kg bodyweight has been recommended for strength and endurance athletes undertaking heavy training.[112-114] However, athletes in some sports (e.g. cycling) often exceed these protein levels when undertaking substantial training, largely as a by-product of high energy intakes.[115] Sustenance is a significant component of training in special case situations such as travel, altitude, hot and humid environments where hydration becomes a factor in performance.[116] A comprehensive and adequate diet that is well timed in its administration is a building block for a stable health platform and a sound recovery programme, as well as being important for growth and maturation.[65] An extension of the term 'sustenance' should include the growing area of all strategies aimed at initiating, ensuing, or maximising both general and specific recovery and regeneration, thereby aiding the underlying well-being of the athlete. Such strategies may transcend the traditional boundaries of training and performance. Strategies may include psycho-physiological activities, neuromuscular stimulation, the use of thermoregulatory stimuli, and the manipulation of environmental or ambient conditions.

4. Training Cycles and Strategies

Optimal performance strategy centres around the problem of how to design a programme within an annual plan that: (i) maximises performance potential at a known future date; and (ii) minimises the risk of fatigue and over-training during the period of training leading up to that date.[117-119] It is well established that in order to attain a significant improvement in performance, training should follow a cyclic pattern.[9,66] The development of performance is achieved by the systematic change in training load parameters of which volume and intensity are the most general training characteristics. Programmes in which athletes are subjected to a steady regular load are discouraged.[9] Furthermore, it has been suggested that training monotony and high training loads may be factors related to negative adaptations to training.[120] The requirement that training loads be administered in a logical fashion to promote training adaptation and prevent overtraining implies a systematic and well-planned approach to the development of a training programme.[6] Periodisation is a process of planning that enables the utilisation of correct loads and adequate regeneration periods for avoiding excessive fatigue. It is a systematic and methodological planning tool that serves as a directional template for both athlete and coach. The concept is not a rigid one with only one form of approach; rather, it is a framework within and around which a coach and sport science team can formulate a programme for a specific situation.[65] Periodisation provides the structure for controlling the stress and regeneration that is essential for training improvements. Planning assists in achieving regularity in the training process and lifestyle, and decreases the danger of monotony and mental saturation through variation despite high training frequency.[9] The periodisation model also lends itself to the establishment of performance objectives, training emphasis and test standards for each phase of training, thereby eliminating the random approach that may lead to excessive increases of volume or intensity, and insufficient regeneration.[6] Further in-depth commentaries on periodisation have been written by Satori and Tschiene,[121] Nádori and Granek,[122] Balyi,[123] Verkhoshansky,[124] Bompa,[10] and Siff and Verkhoshansky.[11]

4.1 Training Structure

Periodisation is the division of a training year into manageable phases with the objective of improving performance for a peak(s) at a predetermined time(s). Annual plans are normally constructed around the number of competitive phases in a year. For those sports that have one competitive phase such as speed skating and other winter sports, the plan is monocyclic and traditionally divided into preparatory, competitive, and transition or recovery phases. For sports that have winter and summer competitive schedules (e.g. track-and-field and swimming), the organisation is bi-cyclic. In multicyclic sports, the planning process becomes complicated and decisions have to be made around the most important competitions.[10] Bompa[10] suggests that monocycles should be used for novice and junior athletes, bi-cycles for experienced athletes, and tricycles are only recommended for advanced athletes who have extensive training backgrounds. Too many competitions create significant stress through travel, expectations, social and psychological factors that can lead to under-performance and eventually burnout. Careful construction of the yearly and long-term plans is critical for the development of a successful senior athlete.

4.2 Training Phases

Through questionnaires and practice, the cyclic arrangement of training loads has been shown to produce performance excellence. The formulation of cycles is a complex process and it has become confused by the use of various terminologies. Matveyev[66] listed the cycles as micro, meso and macro where a microcycle referred to a structure of separate training sessions or small grouping of several sessions; mesocycles were a grouping of several microcycles with a predetermined training objective or performance goal; and macrocycles reflected groupings of mesocycles within a semiannual or annual plan. Bompa[10] and Pyne,[125] on the other hand, use the term 'microcycle' for the weekly training plan and 'macrocycle' as representing a phase of 2–6 weeks. The term 'mesocycle' is not used by Bompa,[10] and Pyne[125] states that mesocycles represent an entire season or time period of 16–24 weeks. Microcycles of training are normally considered to consist of 6 days of training and one rest day; five and two; four and one; or three and one.[1]

A classification system of specific microcycles has been proposed:

- ordinary, moderate microcycle (intermediate training load);
- shock microcycle (significant increase in load to previous microcycle);
- applied microcycle (to allow athlete to adjust to new training conditions or to ensure competition preparedness);
- competition microcycle;
- recovery microcycles (microcycles after competition or shock cycles).[66]

Shock microcycles (increased volume and/or intensity) are necessary to elicit a training overload but must be monitored carefully to avoid injury or overtraining. The lengths of microcycles will vary between sports, and coaches may use different combinations to produce effective competitive performance. Typical cycles follow a pattern with the alternation of training load and relative recovery in a format such as 1 **:** 1, 2 **:** 1, 3 **:** 1 or 4 **:** 1.[3] These cycles are represented in figure 4.

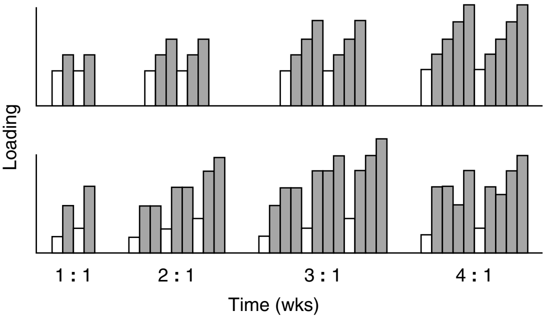

Fig. 4. Examples of training cycles.[3]

A criterion for determining the length of a mesocycle may be based on whether a training objective is metabolic or neural in nature.[122] Longer cycles are suggested for metabolic training and shorter ones for neural adaptation purposes.

4.3 Tapering Strategies

Tapering is used to describe a reduction in training after high-intensity and/or volume training prior to an athletic event in order to allow recovery and enhance performance. Variables that can be altered during tapering include training frequency, duration of training sessions (volume), intensity, and the length of time for which the training load is reduced. Furthermore, various formats of the taper include: a single step reduction in training load;[126-128] an incremental step-wise reduction;[129] or a fast or slow exponential taper.[130,131]

Tapers that improve swim performance often consist of a 60–90% reduction in weekly training volume.[129] However, in distance runners, a 7-day, 62% reduction in weekly training volume did not improve performance as determined by an exercise test to exhaustion when intensity was also low.[13] In contrast, a 7-day taper with an overall 85% reduction in weekly training volume improved 5km race time.[132]

The Shepley et al.[13] and Houmard et al.[132] studies illustrate the equivocal stance of the scientific literature when examining investigations in this area. However, despite a bewildering array of findings, a number of key tenants do percolate through the taper area. Exercise intensity during a taper appears to be the key factor. In studies that utilised exercise intensities of ≤70% $\dot{V}O_{2max}$, either maintained or worsened performance was attained.[133,134] Alternatively, in tapers including exercise intensities ≥90% $\dot{V}O_{2max}$[13,135] or maintained high-intensity strength training[136] have resulted in improved performance. Furthermore, with a 90% reduction in training volume during 7 days that included high-intensity intervals, there was a 22% improvement in exercise time (approximately 5 minutes) to exhaustion.[13] A key suggestion is that intense exercise may be necessary to maintain training-associated adaptations with a reduction in training volume during the taper period.[129]

Taper duration depends on the pre-taper training volume and intensity, and is generally 7–21 days in length. For endurance athletes specifically, a taper that lasts longer than 21 days would result in maintenance rather than an improvement in performance.[137] Mathematical models developed to calculate the optimal combination of frequency, volume, intensity and duration needed for an effective taper suggest that fitness level of an athlete influences the taper duration. An approximate duration of 16 days or less is suggested before a loss of training-associated adaptation takes place.[100,138] However, Fitz-Clarke et al.[138] suggest that if an athlete has a relatively low fitness level, a fast taper is required with a reduced training stimulus for 6–10 days or alternate days of rest and moderate training through 10 days.

Finally, the taper format influences the performance outcome. Recently, four different taper profiles: step reduction versus exponential decay ($\tau = 5$ days) and fast exponential decay ($\tau = 4$ days) versus slow exponential decay ($\tau = 8$ days) were stimulated in a systems model to predict performance resulting from a standard square-wave quantity of training for 28 days.[131] The results of the stimulation were tested experimentally in field trials with triathletes. The results showed that the exponential taper group made significantly greater improvement above the pre-taper standard than the step-reduction group in cycle ergometry, and was better, but not significantly so, in a 5km run. A fast taper group performed significantly better in maximal cycle ergometry than the slow exponential group and was improved more than, but not significantly so, in a 5km run. The results demonstrate that an exponential decay taper protocol following a standard square-wave quantity of training is superior to a step-decrement taper.[131] In summary, it appears that a successful taper involves a significant reduction in training volume by a range of 60–90% depending on pre-taper training and the fitness level of the athlete over a 7–21 day period. Training intensity should be maintained at or above 90% $\dot{V}O_{2max}$ to maintain the fitness component. Unfortunately, to date, there has not been a definitive study or series of studies on the optimal reductions in frequency, duration, intensity and format. However, a comprehensive review of the taper variables has summarised study findings.[139]

5. The Training Response

5.1 Monitoring the Training Response

It is extremely difficult to measure and quantify all input factors affecting an athlete and to assess how the body has integrated the stimuli in determining a measured output response. Aside from the growing knowledge surrounding genetic predisposition (see section 1.2), researchers have discussed a number of parameters in the literature with potential for monitoring the training responses. Smith and Norris[140] have suggested that the ratio between glutamine (Gm) and glutamate (Ga) blood concentrations may be an indicator of tolerance to training. Athletes that have a relatively low Gm/Ga ratio under conditions of low training volume at the beginning of a macrocycle following a rest period, appear to be more susceptible to over-reaching and overtraining than those athletes who have high ratios. Furthermore, most endurance athletes appear to demonstrate high Gm/Ga ratios and tolerate training well. Other relationships between training and different hormonal levels have been established, such as norepinephrine,[141] testosterone[142,143] and biological markers such as iron.[118] Salivary immunoglobulin-A (IgA) has also been suggested as a marker for identifying athletes who are more prone to upper respiratory tract infections.[144,145] Normally, post-exercise salivary IgA levels are lower than pre-exercise, and recovery occurs within 24 hours but may remain depressed for longer periods after high-intensity training.[146] Endurance athletes appear to be at a considerably higher risk of developing infections than power sports or mixed type of sport.[147] In a 12-month study, athletes adhering to a healthier lifestyle significantly reduced infections compared with those reporting daily stress, lack of nutritional awareness or lack of sleep.[147] Thus, an athlete's biochemical profile may assist a coach or sport scientist in characterising athletes for specific suitable training regimes. However, these techniques require performance efforts and blood tests that are not usually endorsed by coaches as they may infringe upon training particularly if maximal efforts are necessary.

Recent scientific advances in heart rate variability (HRV) analysis show promise as a non-invasive resting measurement tool for assessing the degrees of fatigue and preparedness for performance. HRV, a marker of parasympathetic activity, is an accepted term to describe variations of both instantaneous heart rate and RR-interval,[148] and the rhythmic periodicity of the sinoatrial neural discharge appears to vary with respiration.[149] Furthermore, circulatory function is modulated through the interplay of sympathetic and parasympathetic outflow and is viewed as a reciprocal phenomenon.[149] One of the most pronounced cardiovascular adaptations to endurance training is a lowered resting heart rate, which has been proposed to occur through an increase in parasympathetic or vagal tone.[150,151] However, training and extraneous stressors can induce changes in autonomic function[152,153] that result in under-performance of an athlete even after an appropriate regeneration period. An increase in resting heart rate has been suggested as a marker for monitoring under-recovery,[154,155] but an increase in a few beats, which may be statistically significant, is of limited practical value due to their dependence on numerous environmental factors and mental stress. In contrast, the advantages of HRV indices, using Fourier or wavelet analysis, lie in their magnifying variations in the autonomic nervous system activity, which makes them more useable and reliable.[156] HRV indices include: the high-frequency (HF) peak of the spectrum (0.15–0.40Hz), which represents parasympathetic activity; the low frequency (LF) peak of the spectrum (0.04–0.15Hz) represents both parasympathetic and sympathetic activities;[148] and sympathovagal balance is expressed as a percentage of LF/HF.

In a study of young and middle-aged mixed sex recreational runners, a 12-week running programme, which included two tapers, resulted in a significant increase in HRV, total power and high-frequency power in all groups. The data indicated that HRV measurement appears to provide an effective non-invasive assessment of cardiovascular adaptation to aerobic training.[157] Other recent training studies have found an increase in sympathetic tone in endurance athletes at the end of a 6–9 week overtraining protocol,[158] and 3 weeks of heavy training shifted the cardiac autonomic balance towards a predominance of the sympathetic over the parasympathetic drive.[156] In the latter study, during a recovery week following the heavy training, there was an abrupt compensation marked by a dramatic increase in HRV, associated with a relative increase in the parasympathetic drive and a decrease in the sympathetic drive.[156] As a long-term database is built on an athlete, the measurement of HRV may provide a monitoring tool that minimises the number of athletes who do not realise their performance potential due to inappropriate training.

The comprehensive monitoring of athletes requires the formation of a sport science/medical team to provide the coach with detailed information at both the individual athlete and group levels in order to assist the coach to make informed decisions regarding the effects and consequent planning of training. A multidisciplinary team of dedicated professionals should consist of strength trainers, nutritionists, massage therapists, physicians, sport psychologists and others depending on the nature of the sport. It is advisable to have a qualified individual (lead sport scientist) with a good working relationship with the coach, to act as a funnel for information in order to provide him/her with an ongoing synopsis of the circumstances surrounding a training group or individual athlete.[65]

5.2 Errors in Training

Within any training squad, there will be athletes who will respond favourably or only marginally to a training programme depending on the type of athlete and their ability to cope with the training demands and non-training stress factors. The sequence of training and the interplay between work and recovery are critical elements of attaining a desired training response. Faults in the training process were initially summarised by Harre[9] and have been discussed by several authors.[10,65,101] Errors in training include:

- Recovery is often neglected with mistakes in the micro- and macrocycle sequence. There is inadequate use of general exercise sessions for recovery purposes.
- Demands on an athlete are made too quickly relative to capacity, compromising the adaptive process.
- After a break in training due to illness or injury, the training load is increased too rapidly.
- High volume of both maximal and submaximal intensity training.
- The overall volume of intense training is too high when the athlete is primarily engaged in an endurance sport.
- Excessive attention and time are spent in complex technical or mental aspects without adequate recovery or down time.
- Excessive number of competitions with maximum physical and psychological demands combined with frequent disturbance of the daily routine and insufficient training.
- Bias of training methodology with insufficient balance.
- The athlete lacks trust in the coach due to high expectations or goal setting which has led to frequent performance failure.

The underlying theme of these errors is the imbalance between intensity and adequate recovery, which together with an inappropriate lifestyle or social environment can lead to a situation of overtraining.

5.3 Overtraining

In its simplest form, overtraining has been described as an imbalance between training and recovery,[14] and a range of terms have been used to describe it. The terms most often used include: staleness, burnout, overreaching, and short- and long-term overtraining.[159] Staleness is an initial failure of the body's adaptive mechanisms to cope with psychological and physiological stress.[160] It is a state in which the athlete has difficulty maintaining standard training regimens and can no longer achieve previous performance results.[161] Staleness can be regarded as an undesirable response that is a consequence or product of overtraining.[60,162] A state of chronically depressed performance accompanied by some of the more serious symptoms of overtraining has been termed the 'overtraining syndrome'[6] and is considered to be synonymous with staleness.[14] Burnout, on the other hand, can be considered more severe than staleness[163] and is defined as a psychological, emotional and physical withdrawal from formerly pursued and enjoyable sport as a result of chronic stress.[164] Overreaching or short-term overtraining is an accumulation of training and non-training stress and is characterised by transient performance incompetence which is reversible within a short-term recovery period of 1–2 weeks and can be rewarded by a state of supercompensation.[155] Sufficient high levels of overload training that push an athlete into an overreached state are a normal and necessary part of the training process.[165] However, if an athlete is not monitored closely, the short-term fatigued state can often turn into long-term overtraining. Overtraining is a long-lasting performance incompetence which lasts 3 weeks or more[166] due to an imbalance of training load, competition, non-training stressors and recovery.[7] In addition to performance incompetence, athletes exhibit an alteration in well-being rating[60,167,168] and may show an increased rate of infections.[8] Conditions that may result in overtraining include errors in the training methods used, lifestyle, social environment of the athlete and health-related problems.

Since improvement in performance is the specific goal of training, performance should be the gold standard for the training and overtraining reaction.[7] The diagnosis of an overtraining syndrome, or staleness, is based on the demonstration of decreased sport-specific performance with more or less pronounced mood disturbances after the exclusion of an organic disease.[169] Performance can be practically determined as maximum peak power, speed or time of a race distance, or under-distance, or time to exhaustion for a given speed or power.[7] In ergometric studies, overtrained endurance athletes show an impaired maximal lactate production and reduced time to exhaustion in high-intensity endurance exercises,[168,170] while the submaximal lactate-performance relation and the resulting anaerobic threshold as well as the anaerobic alactic performance remain relatively unchanged.[169] Despite a wide array of markers[6,169] and tools for diagnosing overtraining, there is currently no single marker. The duration of the short-endurance stress test, the maximal lactate concentration of the incremental graded exercise, as well as the altered mood profile, appear to be the most sensitive parameters.[168]

6. Optimal Performance

Optimal performance requires integration of not only the physiological elements, but also of the psychological, technical and tactical components.[66] An integrated athletic performance is also affected by a health factor and the final performance outcome requires all components to function at near optimal levels on the day of competition. A problem is that top-class athletes and their coaches constantly protract both the volume and intensity of training in order to find an edge in competition. Many great champions in a variety of endurance sports have had the extraordinary ability to tolerate significant training levels that are beyond the level of their contemporaries and that prove devastating when other athletes attempt to replicate the champion's programme.[79] Thus, the risk of overtraining is significant particularly when the principle of individual differences is applied to athletes or teams. The principle of individualisation suggests that athletes will react and adapt differently over individual time frames even when presented with identical training regimes.[11,65] During a training cycle, an athlete is in a constant flux along a continuum from negative and positive responses and a state of overtraining may exist towards the end of a cycle when sufficient recovery is excluded from the training process. At competition time, a state of under-recovery may prevail even with a taper as fatigue may have been too great to recover from in the usual taper period. Under-recovery refers to a failure to fulfil current recovery demands[59] that may result from either training and/or non-training stress. Under-performance is performance incompetence where an athlete is unable to execute practiced skills in competition or training at expected levels based on previously established performance/training criteria. Under-performance is a consistent unexplained performance deficit (recognised and agreed upon by the coach and athlete) despite 2 weeks of relative rest.[171] However, it cannot be assumed that under-performance is a result of inappropriate physical training alone. Under-performance can result from either insufficient recovery or from prolonged recovery which can lead to detraining. Furthermore, other factors such as psychological stress, the type of recovery activity, travel, personality and sociological issues must be part of a multi-faceted model.[172]

6.1 An Integrated Model of Athletic Performance

Despite the notion that physical performance is the ultimate goal of training, sport scientists have realised that athletes may encounter stress from three basic sources that are physiological, psychological and social in origin. Thus, the athlete is a living, psychosociophysiological system.[173] Performance development and optimal training depend heavily on the ability to integrate and react to as many relevant variables as possible. Therefore, there is a requirement for a holistic approach to

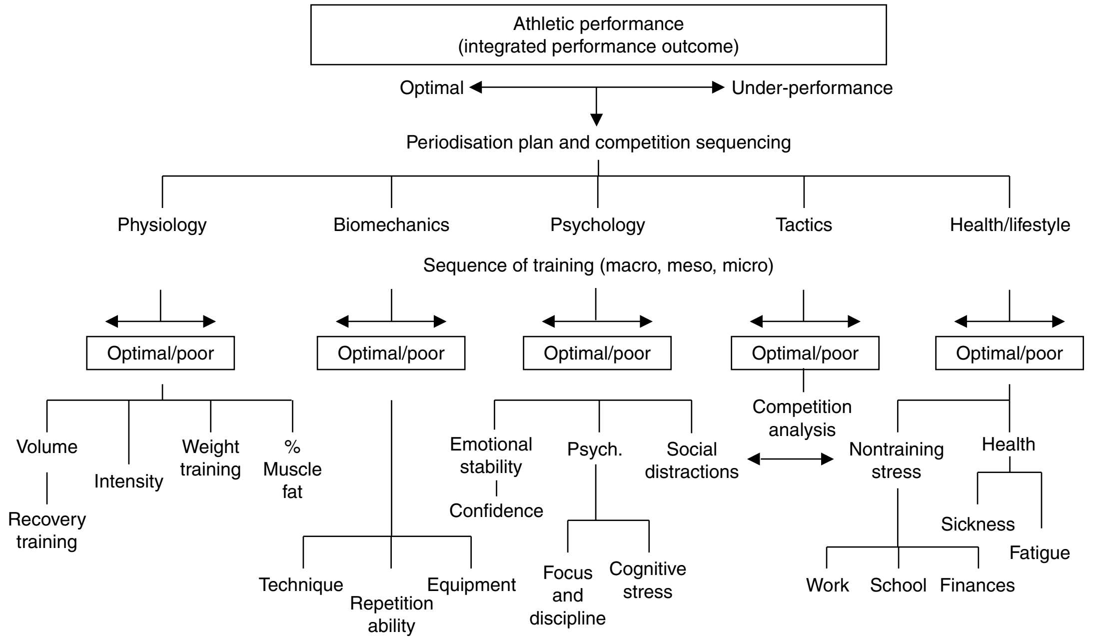

Fig. 5. A model of the contributing components to a measurable sport performance outcome called 'athletic performance'. **Psych** = psychological.

monitoring instead of focusing solely on single variables such as training load.[174] The ultimate goal of monitoring is to give each element the appropriate degree of individual attention while simultaneously watching and guiding all others. Furthermore, when necessary, knowledge about non-training stressors will assist athletes and their coaches to adjust the physical training load in relation to variations in total stress experienced.[174] A model representing factors that influence athletic performance is presented in figure 5.[175]

Within the athletic performance model, competition sequencing has a central position. Although competition can be regarded as the highest form of training stimulus, excessive competition, particularly in a short period of time, can lead to underperformance. The demands of the competitive environment, intensity and psychological stress can provide a stimulus to the training process, but insufficient recovery can push an athlete towards the overtraining syndrome. In many sports today, at both the junior and senior levels, the competition calendar is not based on a periodised plan, promoting peaking at a major competition, but on money and entertainment. It is important for coaches, where possible, to carefully select appropriate in-season competition opportunities as specific training to challenge an athlete and to provide an evaluation of training state.

The five components (physiology, biomechanics, psychology, tactics and heath/lifestyle) should be evaluated at in-season competitions, and final tapered and peaked performance times on a scale from optimal to poor in order to determine the effectiveness of training. In order to establish the support system to truly push the limits of performance, a formal systematic evaluation and planning process should occur at the end of each macrocycle or season (6 months). The process rotates from initial planning, implementation, training, performance and evaluation to the formulation of the next new plan.[67] Balyi[67] suggests when evaluating both the training and performance parameters, the following questions can assist in the development of the new plan:

- What were the objectives of the previous plan?

- What actually happened and were the objectives met?
- What was learned?
- What should be done next to sustain/develop strengths and improve weaknesses?
- Who needs to be informed about the new plan and strategies of training?

Without this systematic approach, the long-term plan will not lead to optimal performance and will certainly obstruct the ability to repeat the series of events and conditions that led to a peak performance in subsequent cycles.

6.2 Avoiding Overtraining

Training strategies for avoiding overtraining have been summarised by several authors.[6,56,79] Common training themes for endurance athletes include: low-intensity endurance training as a necessary platform for higher intensity specific training;[9,94] alternate hard and easy training;[56,92] training based upon only 2–3 hard sessions per week;[92,94] training intensity as the key to success;[79,80] and rest and recovery as necessary before competitions.[56] These themes go hand in hand with common features of structured training programmes as summarised by Pyne[125] where:

- the long-term performance goal for the season forms the basis upon which the training programme is designed;
- there is a progressive and cyclical increase in training load;
- there is a logical sequence to the order of the training phases;
- the training process is supported by scientific monitoring;
- there is intensive use of recovery techniques throughout the training programme;
- there is an emphasis on skill development and refinement maintained throughout the training programme;
- there is an underlying component for the improvement and maintenance of general athletic abilities.

The attainment of consistent high performance requires effective training that is a carefully designed and monitored sequence of physical and mental stresses that are accompanied by planned recovery based on the current level of fitness.[11] Furthermore, the training effect of a programme within a macrocycle is determined not by the sum of the stimuli, but by their interrelation, schedule and time intervals between various stimuli.[176] It is unfortunate that most scientific studies reported in the literature are relatively short term (6–20 weeks), do not use elite athletes, and suggest that the dose-response (biological impact) is predictable and if repeated will produce the same response. The impact of a training load is determined by current (pre-training cycle) fitness/fatigue ratio, performance development status (level of sport mastery), and the sequence and duration of the applied load. Since an athlete's fitness and performance status are dynamic and usually moving in a positive performance direction, it is likely that any dose-response will not produce a uniform and predictable adaptation when continually repeated. Thus, the training response necessitates continual monitoring in order for adjustment of the applied training to maximise the individual training effect.

7. Conclusions

The limits of human performance are continually being challenged through, among other reasons, year-round training and an advanced knowledge of training methodology. Sport performance requires an athlete to integrate many factors, some trainable (psychology, physiology and skill), some teachable (tactics) and others outside the control of the athlete and coach (genetics and age). Although genetic endowment is a common-sense explanation of what underlies performance in sport, an alternative position is that sport expertise could be the result of hours spent in focused training or deliberate practice. Thus, at the highest levels of sport, there are genetically talented 'thoroughbreds' and other athletes who have a highly developed work ethic ('work horses') with a system guiding their effort.

Long-term training spans a period between 10–15 years of an athlete's competitive life and is divided into phases not by age but by the degree of their advancing ability. A distinct characteristic of long-term plans is the inclusion of multi-activity physical preparation. The training process involves the manipulation of the training variables: intensity, duration, and frequency, with training load being the combination of all three elements. Athletic performance incorporates the basic physiological components of strength, speed and endurance where training has developed sport-specific qualities of these components. Additional components of training include skill, psychology, suppleness, physique and sustenance.

The development of performance is achieved by the systemic change in training to promote training adaptation and prevent overtraining through the utilisation of correct loads and adequate regeneration periods. This is accomplished through periodisation, which is the division of a training year into manageable training phases with the objective of improving performance with a peak at a pre-determined time. Training phases are structured as macro-, meso- or microcycles where the length of a cycle is usually based on whether a training objective is metabolic or neural in nature and the competitive calendar.

The comprehensive monitoring of athletes is necessary particularly during phases of training overload in order to allow a coach to make informed decisions regarding the effects and consequent planning of training. The principle of individualisation suggests that athletes will react and adapt differently over individual time frames even when presented with identical training regimes. A formal evaluation and planning process should occur at the end of each macrocycle, rotating through initial planning, implementation, training, performance and evaluation to the formulation of the next plan. The attainment of consistent high performance requires effective training that is carefully designed and monitored and is accompanied by planned recovery.

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