TOPICS IN EXERCISE SCIENCE AND KINESIOLOGY

Implementation Strategies

The Pursuit of Peak Athletic Performance

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ABSTRACT

Topics in Exercise Science and Kinesiology Volume 4: Issue 1, Article 3, 2023. Achieving peak performance in sports is a multifactorial phenomenon that spans several scientific disciplines. The optimization of human performance requires a comprehensive and systematic assessment that identifies potential performance-inhibiting factors. The result of such analysis allows for more individualized and accurate evaluation, athlete monitoring, and training interventions. Thus, there is a need for a multidisciplinary model of peak performance to guide practitioners when conducting a comprehensive analysis. The purpose of this manuscript is to provide a brief but practical vade mecum for practitioners to consider in the development of a training system while pursuing peak athletic performance.

KEY WORDS: Sport performance, training, peak performance, training model, training system

INTRODUCTION

Optimizing human performance requires a harmonious balance between training (stress) and recovery (adaptation) with careful consideration of performance-limiting factors (task, environmental, and human)(1). Achieving peak performance in sports is a multifactorial phenomenon that spans the scientific disciplines of genetics, bioenergetics, nutrition, physiology, biomechanics, psychology, tactics, health, and social sciences. In this context, peak performance is defined as an individual's best theoretical performance capacity, within the scope of their sport, genetic potential, training status, and performance-limiting factors. An exercising human is a complex biological machine that requires a vast number of physiological events to occur simultaneously. However, only a few physiological processes control and limit the overall performance in a given task. Thus, sports practitioners and athletes who want to maximize performance must have a foundational understanding of physiological processes that limit performance. In sports settings, successful practitioners systematically identify performance-limiting factors through detailed needs analysis and improve the individual's capacity to perform that process (2).

A needs analysis includes an in-depth assessment of the physical demands of the individual's life and sport with consideration of their physical and mental profile (3), which allows for the identification of key performance indicators (KPIs) that can be used to evaluate the success of an individual or team meeting a performance objective (e.g. 4-minute mile)(4). KPI identification requires that practitioners use a data-driven approach which includes comprehensive analysis, benchmarking (comparisons between individual athletes, team averages, and normative values), and setting desired performance outcomes. Once an athlete's/team's strengths and weaknesses are identified, detailed training plans and interventions can be constructed and deployed. A true science-based practitioner will introduce training stimuli and systematically evaluate the response pre-post. Thus, the scientific method must be rigorously followed to review the effectiveness of interventions in the pursuit of peak performance.

The purpose of this manuscript is to provide a brief but practical vade mecum for practitioners to consider in the development of a training system (Figure 1.). Genetics are likely the primary limiting factor in the pursuit of peak athletic performance, given the capacity to influence the ability to produce training stress, recover from exercise stimuli, and dictate performance limiting factors (e.g. fiber type composition). Thus, genetics sits at the top of the model, with training stress, recovery and adaptation, and limiting factors presented as a subheading of genetics (Figure 1). In this context, a performance limiting factor can be defined as an individual or systematic constraint that interferes with an athlete's performance. Figure 1 highlights multidisciplinary performance limiting factors, providing practitioners a check-list like tool to address when creating a training system. Key concepts to consider lie beneath each limiting factor (Figure 1.) and are described throughout this manuscript in respective subsections. Given the vast amount of sports settings, an exhaustive review is outside the scope of this manuscript. However, this article is designed to aid in the thought process behind creating a training system in pursuit of peak athletic performance, which may be applied to various sporting contexts across the spectrum of performance levels (from youth to elite) and in both male, and female athletes. For example, a sports scientist for a collegiate American Football team could use this model as a checklist-like tool to aid in the needs analysis process and address potential performance-limiting factors. After this assessment, the practitioner may decide to implement specific strategies or interventions (which are included in the following respective sections) that may target and enhance performance-limiting factors, ultimately improving athletic performance. Focus is directed towards modifiable limiting factors rather than non-modifiable determinants of performance.

METHODS

This study utilized a literature search to identify relevant manuscripts addressing the relationships between training, recovery, and performance-limiting factors with peak athletic performance. Literature searches were performed using electronic databases: PubMed and Google Scholar. These searches used various combinations of search terms, including: section headings and subheadings (e.g. genetics), athletic performance, sport, peak performance model, training, recovery, and review. The literature search included manuscripts published in the English language from peer-reviewed journals including study designs such as: narrative reviews, systematic reviews, meta-analyses, randomized control trials, quasi-experimental methods, and mixed methods. All databases were searched within the time frame from September to December 2022. Reference lists of all full-text articles found in the initial database searches were also utilized to identify relevant resources. The exclusion criteria were: articles that did not have a full text available, and were not in English. The model (Figure 1) was developed based on empirical evidence and careful examination of the curriculum taught at universities recognized by the National Strength and Conditioning Association Education Recognition Program.

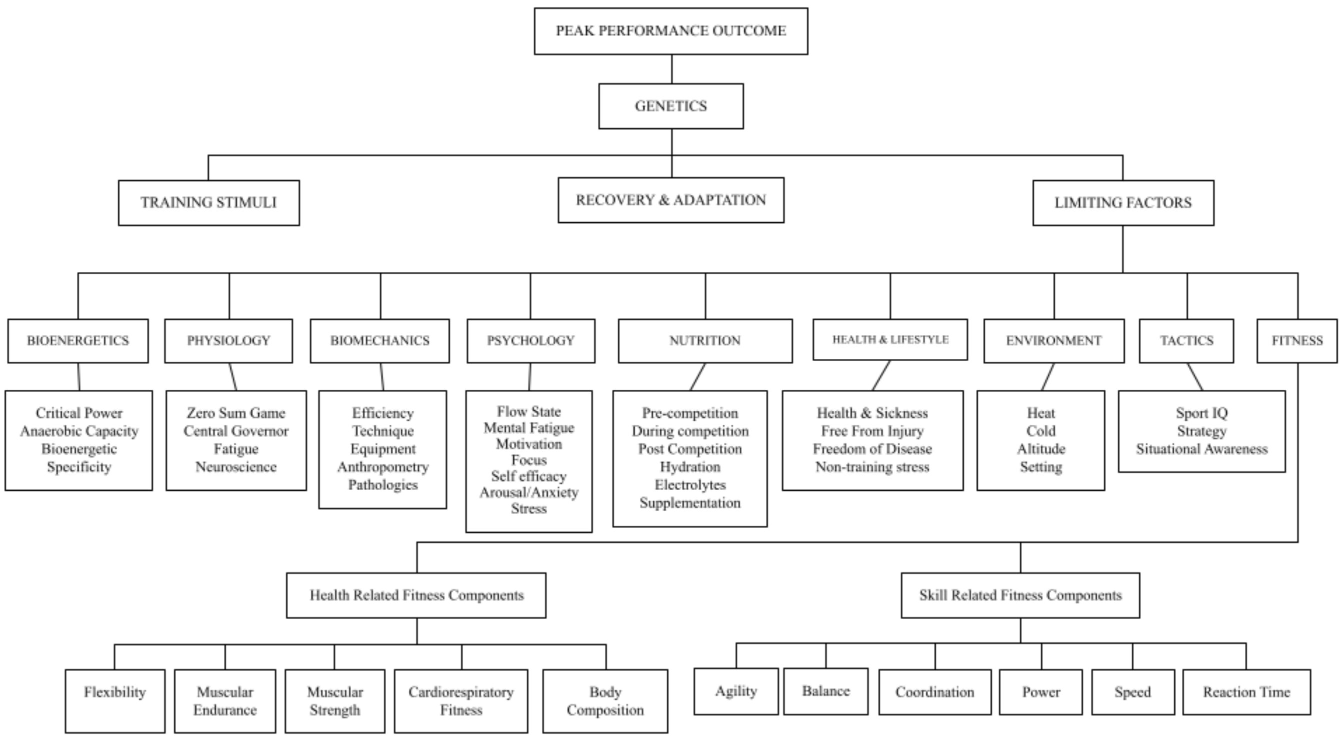

Figure 1. A checklist-like tool for sports practitioners in consideration of systematically developing a training system while pursuing peak athletic performance. Concepts are presented as potential performance-limiting factors.

GENETICS

Nature and nurture are so closely intertwined that the determinants of optimal human performance lie within both constructs. Genetics influence the ability of the human body to produce training stress, how the body recovers and adapts to that stress, and partially determines which limiting factors provide resistance to obtaining peak performance. Therefore, genetics are likely the primary limiting factor in the pursuit of athletic performance (Figure 1.) It is widely accepted that any individual who is dedicated to an organized training system can improve athletic performance (5). However, not all individuals may reach the upper echelon of athletic performance based on their genetic profile, regardless of dedication to years of a highly organized training system (5). Numerous interdependent physiological and biochemical systems must function optimally to allow for peak performance, indicating that it is highly unlikely that a single gene is associated with superior athletic performance (6). Ultimately, elite athletic performance is a polygenic trait, meaning that it is influenced by more than one gene (6). Peak performance is the result of the interaction between both genetic and training factors, where individual performance thresholds are determined by genetics, and training is the process by which genetic potential is realized (6).

TRAINING STRESS

The physiological pattern of response to training stimuli (stress) is best described by Selye's general adaptation syndrome (7), which provides a framework for understanding the effect of training stimuli on performance. As a training stimulus is presented, performance decreases due to an acute fatigue response, followed by recovery and adaptation. In ideal training conditions, the adaptation results in super compensation, whereby performance is enhanced (8). However, training stimuli applied too frequently or at too great of an intensity can result in overtraining or exhaustion, decreasing performance potential (9). In contrast, providing inadequate training stimuli will not result in enhanced levels of performance. Therefore, peak performance requires a harmonious balance between training stress and recovery, which is subjective in nature for each athlete.

It is critical to note that "training" is not exclusive to exercise stimuli, but encompasses all stimuli that are presented to an athlete. Interestingly, mental fatigue impairs physical performance in humans (10, 11). Therefore, consideration of mental stimuli such as work or an academic exam should also be considered before training or competition. Optimization of exercise training stimuli requires consideration of the basic principles in exercise science (principle of individuality, principle of specificity, principle of overload, principle of progression, principle of diminishing returns, and the principle of reversibility)(3). Specific training stimuli are discussed later (see fitness).

RECOVERY

Recovery from training stimuli is an essential component of the overall training system. Strategies that minimize fatigue and/or accelerate recovery after training stimuli are beneficial in preparing an athlete for another training stimulus or competition (12). However, too much recovery can result in insufficient training stress, and blunting adaptation. Therefore, consideration of the time course of the response to training stress for specific variables of interest is essential. Generally, voluntary activation of muscle returns ~24 hours after training, carbohydrates are depleted during exercise and restored ~72-120 hours after exercise, muscle damage and inflammation peaks a few hours after training and remain present for ~96-120 hours, and muscle soreness (DOMS) peak around 24-48 hours but remains present up to ~120 hours (12). Recovery strategies include but are not limited to mobilization (13, 14), foam rolling (15–17), massage (18), percussion therapy (19), sleep (20), heat/cold (21, 22), and compression (23–25). The optimal implementation of recovery strategies is complex, and challenging, and may need to be individualized based on an athlete's preferences, which adds to the depth of the model. Practitioners are directed towards exploring techniques such as the 100-point weekly recovery checklist (26).

LIMITING FACTORS

The systematic identification of performance-limiting factors and the ability to systematically induce positive adaptations is essential in the pursuit of peak performance. Comprehensive athletic profiling that includes benchmarking is necessary to identify performance limiting factors, which allows for the optimization of training stimuli, recovery, and adaptation. Practitioners are directed towards comprehensive athletic testing and benchmarking, which includes a needs analysis of the physical, mental, and environmental demands of sport (3). Benchmarking refers to the comparison of an athlete or team's performance against a performance norm or standard (4). Individual or team strengths and weaknesses will be presented, allowing for data-driven decisions on the prioritization and inclusion of specific training stimuli or interventions.

BIOENERGETICS

Bioenergetics is the study of energy flow through living systems (27). Locomotion requires the conversion of metabolic energy to mechanical work. The sustainability of the metabolic energy supply matching the required mechanical work can present itself as a performance limiting factor, resulting in decreased force production (1). The curvilinear relationship between power output and the time for which it can be sustained represents the critical power (CP) concept (28, 29). CP essentially represents a maximal metabolic rate (28), above which fatigue is inevitable. Below CP, the energetic demands of mechanical work are met by metabolic energy, demonstrated by steady-state values for muscle metabolites (28). In some sports, peak performance may be determined by the individual's ability to produce energy (ATP) in the specific metabolic pathway that predominates the activity (30). Therefore, consideration of a sports bioenergetic demand is essential to progress towards peak performance. Training should include intensities above, at, and below average mechanical power requirements for durations that match the requirement of task performance.

EXERCISE PHYSIOLOGY

From a physiological perspective, enhanced performance in sports can be explained by superior cardiovascular, neural, hormonal, and muscular systems. The cardiovascular/anaerobic model of maximal exercise performance describes that endurance performance is determined by the capacity of the cardiorespiratory system to provide large amounts of oxygenated blood to working muscles (30). Thus, training to improve maximal oxygen uptake (VO2 max), cardiac output, skeletal muscle capillarization, and mitochondrial mass/density will enhance endurance performance (30). Furthermore, optimum training would maximize the efficiency and contractility of both the heart and skeletal muscle (30). Thus, the processes involved in muscle recruitment, excitation, and contraction can limit performance. Ultimately, an individual's ability to resist central and peripheral fatigue will have a significant impact in most sports settings.

The Central Governor Model of Exercise Regulation explains that the action of a central (brain) neural control system regulates performance specifically to prevent biological harm (31). In essence, the body is constantly sending feedback to the brain about the status of physiological systems via peripheral receptors (thermoregulation, energy availability, acidity, etc.). If any of the aforementioned signals are perceived to result in significant biological harm, exercise performance will be regulated so that the body can shift towards regaining homeostasis. Therefore, consideration of proprioceptive mechanisms that signal the brain and their desensitization (e.g. heat acclimation) may allow for enhanced sports performance.

Zero-sum game. The application of the zero-sum game, a mathematical representation of a situation that involves multiple sides where the result is an advantage for one side and an equivalent loss for the other (32), can be applied to exercise physiology. A human muscle cell, including mitochondria, contractile elements, and a sarcoplasm in which anaerobic metabolism occurs, is perfectly adapted to the stimulus it responds to. For example, endurance-like stimuli will shift the muscle cell towards optimizing mitochondrial volume and density, while decreasing the volume of non-fatigue-resistant contractile properties and increasing aerobic capacity. Furthermore, strength training stimuli will increase contractile elements at the expense of mitochondrial volume. At its base, an understanding of the zero-sum game and its application to exercise physiology is essential for the attainment of peak performance.

Neuroscience. The human nervous system can rearrange itself and change throughout the lifespan, representing the concept of neuroplasticity which is based on the mechanisms of synaptic potentiation and depression (4)**.** Modern athletes go to great lengths to optimize their bodies, but generally exclude prioritization of training the brain. Considerations should be made for training the brain to commit motor skills to automaticity and improve situation-specific sport processing capabilities (4).

BIOMECHANICS

Sports biomechanics and computer simulations provide a powerful tool for the analysis of the underlying mechanics of the technique. Once the underlying biomechanical nature of an individual is established, the technique can be optimized, potentially reducing injury or improving performance. However, due to the multifactorial complexity of human movement (dynamical systems theory) identification of an "optimal" solution for a given motor activity remains elusive (33). In short, there are a lot of ways to get the job done. Not all athletes should, or will perform motor programs the same. With this perspective, individualized assessment of an athlete's efficiency, technique, equipment, and anthropometrics can be made for running, jumping, throwing, and change of direction.

Biomechanical fatigue can become a limiting factor in dynamic intermittent sports (i.e. soccer) and continuous effort sports (endurance running). Repetitive eccentric muscle contractions can disturb muscle function, resulting in a loss of elastic energy production, requiring increased work during the propulsion phase (30). Training to improve elasticity and delay fatigue of the stretch/shortening cycle by altering the elastic component of skeletal muscle, tendons, and ligaments should be considered (30).

Efficiency & economy. The human body is incredibly inefficient, as ~80% of expended energy is lost as heat that needs to be dissipated to avoid increased body temperature (34). Thus, individuals with superior movement economy would improve performance by reducing heat accumulation (30) Trained individuals may be closer to maximum values of efficiency (75%) than untrained individuals for a given motor task, which would indicate trainability of whole body efficiency (2). For example, running economy is a trainable characteristic that improves as runners participate in more training volume, high-intensity interval training, stride frequency manipulation programs, resistance training, plyometric training, and nutrition strategies (35, 36).

Technique can provide resistance to obtaining peak performance in many sports settings. For example, the emergence of the Fosbury flop in high jumping, or the flip turn in swimming resulted in immediate athletic improvement and record-breaking performances. Consideration of different techniques within sports disciplines and which may best fit the athlete is necessary to optimize performance. It is widely accepted that expertise takes practice. Once a technique is identified, deliberate practice and the 10,000 rule should be considered (37).

Equipment utilized in sports has changed significantly over the past century. Drastic improvements in world record 100-meter sprint times parallel improvements in track conditions (cinder to modern economic tracks) and footwear worn by athletes (38). Although, the multifactorial nature of sprint performance makes it challenging to provide evidence for how technology has contributed to such performance (38). An in-depth analysis of equipment utilized in specific sports settings is critical to avoid limitations in performance.

Anthropometrics represent the measurements and proportions of the human body. Although anthropometrics are most likely a result of genetics, socioeconomic status (access to resources) and environmental stresses (holding a tennis racquet for hours a day) do have the capacity to influence body proportions. Considerations of concepts such as the crural index (the ratio of leg length of the lower leg to the thigh) are essential to understanding an individual's performance propensity. For example, higher crural indexes are associated with higher sprint speeds and superior running performance (39) while throwing velocity is associated with upper limb and hand length (40). Although anthropometrics are non-modifiable, consideration of an athlete’s proportions is essential in understanding peak performance capacity.

Pathological mechanisms. Pathologies in human locomotion and motor tasks can be detrimental to performance. Contractures are structural changes within fibrous connective tissue that follow prolonged inactivity or scarring from injury, resulting in inelastic and rigid tissues (41). Insufficient muscular strength as a result of disuse or neurologic impairment can detrimentally affect performance. Impaired motor control, such as sensory loss or spasticity can decrease performance and increase injury risk in sports settings. Lastly, pain (e.g. excessive tissue tension) can cause significant alterations in biomechanical patterns (compensation) exposing an individual to abnormal stresses, decreased efficiency, and increased injury risk (42).

SPORT PSYCHOLOGY

Any model that attempts to drive athletes toward peak performance must include components of psychology. From a mental fatigue perspective, the psychological/motivation model suggests that the ability to sustain exercise performance results from a conscious effort (31). In support of this model, studies that show enhanced performance following a placebo intervention are evident throughout the history of exercise science. It is critical to note that mental fatigue (e.g. a long workday or exam) impairs physical performance in humans (10, 11). Mental fatigue is defined as a psychobiological state that manifests a feeling of lethargy, disinterest, or decreased motivation and results in the reduction of cognitive and/or motor proficiency (4). The flow state, a non-ordinary state of consciousness that drives peak experiences, has emerged as a leading concept in optimizing human athletic performance (4). Strategies for finding flow and managing mental fatigue include the challenge/skills ratio, focus of attention, and neurofeedback approaches (4). Furthermore, optimization of an athlete's arousal, anxiety, stress, self-efficacy, attention, motivation, and focus can result in enhanced athletic performance (3). For example, verbal instructions that promote external vs. internal focus results in significant improvements in the broad jump (43).

NUTRITION

Nutrition plays a key role in providing fuel for training, and nutrients for adaptation and recovery. The development of an environment and culture that reinforces nutritional strategies, and identifies nutritional problems is essential for peak performance. Nutrition is at the epicenter of energy and body composition management. Thus, an understanding of the relationship between energy intake and estimated energy requirements that result in alterations to body composition is foundational to enhancing performance (4). Athletes and practitioners must consider the factors that limit a steady supply of metabolic energy in the specific metabolic pathway that predominates the activity. Fatigue in intermittent high-intensity exercise is often associated with failure to regenerate muscle phosphocreatine and the buildup of acidity, indicating the need for stressing the creatine pathway and buffering capacity in training and consideration of supplementation. For aerobic endurance athletes, the focus should be directed toward sparing finite carbohydrate stores and enhancing the relatively unlimited amount of energy stored in body fat. Adequate hydration is also essential to producing peak performance in athletics. A 2% decrease in body mass due to water loss can reduce both aerobic and intermittent exercise performance (44), as well as decrements in muscular strength and power (45). It is seldom mentioned that water is a substrate in the ATP hydrolysis reaction, and should be considered just as important as ATP itself in the transfer of energy.

Athletes and practitioners are directed to the nutritional recommendations and guidelines presented by the National Strength and Conditioning Association (3, 4). Nutritional strategies for fluid and nutrition intake should be developed considering pre, during, and post-competition/practice. Pre-exercise nutritional strategies should be explored during practice, not competition. Sweat rates should be routinely measured in different environments (heat and cold) to determine the demands of rehydration. Electrolytes should be included in rehydration strategies (4). Lastly, consideration of daily multivitamins and supplements may provide nutritional support when a "perfect" diet is not attainable.

HEALTH AND LIFESTYLE

In contrast to a sports science perspective, a medico-clinical perspective of peak performance requires freedom of disease (2). Thus, consideration of the acute stress exercise places on the immune system is essential to avoid an increased risk of illness (34). Furthermore, non-training stress such as relationships, finances, and work/school should be considered in the balance of stimulus and recovery.

ENVIRONMENT

Heat. Training and competing in the heat have negative implications for both athletic performance and safety. The human body produces a significant amount of heat during exercise (34), highlighting the obvious implications of exercise in the heat and the challenges placed on the thermoregulatory system. Heat stress significantly increases sweat rates and blood flow to the skin, resulting in determinants of athletic performance (34). Thus, the importance of heat acclimatization that induces biological adaptations to reduce thermal and cardiovascular strain is critical for peak athletic performance and safety (34). All individuals in sporting contexts need to have an understanding of the signs and symptoms associated with heat illness to improve participant safety (4). Considerations to improve performance and safety in hot environments should include hydration strategies, cooling strategies, and apparel.

Cold. Training and competing in cold weather environments presents potential negative performance effects and health issues. Cold exposure can affect the ability of the cardiovascular system to deliver oxygen to working muscles, the functioning of the nervous system, and an individual's psychology (46). Detrimental effects of cold exposures have been found in endurance performance, strength, and balance (46). Practical recommendations for endurance and speed-related sports that compete in cold weather can be found in Gaterer et. al., (2021)(46).

Altitude. Training and competing at altitude impairs aerobic endurance performance and repeated intermittent exercise, while short-duration anaerobic exercise may not be affected (4). Strategies to optimize performance at altitude include the live high train high model, the live high train low model, and intermittent hypoxic training (4).

TACTICS

The development of an athlete's tactical skills requires as much effortful practice as other aspects of development (47). Athletes that possess high levels of tactical skills have an advantage that may be displayed as advanced situational awareness in sporting disciplines. From a research perspective, our understanding of how coaches and players go about developing these skills is limited, as most statistics in sports describe motor skills rather than sport-specific intelligence (47). Practitioners are encouraged to develop systematic assessments that examine athletes' understanding of rules, situational awareness, and strategy.

FITNESS

In many sports settings, specific variables associated with an individual's fitness may be a primary limitation of peak performance. The following sections briefly outline components of fitness that should be considered in the design of a training system.

Cardiorespiratory fitness is related to the ability to perform large muscle, dynamic moderate to vigorous intensity exercise for long periods (48). The primarily used modes of testing cardiorespiratory fitness include field tests, graded treadmill tests, and mechanically braked cycle ergometers. Practitioners are encouraged to utilize tests that most closely mimic the requirements of the respective sport. For example, field tests such as the Yo-Yo intermittent recovery test and the maximal aerobic speed test are designed for use in dynamic intermittent sporting contexts. Types of aerobic endurance training programs include long slow distance, pace/tempo, intervals, high-intensity interval training, and fartleks (3).

Anaerobic Capacity. Most dynamic intermittent sports require repetitive accelerations and decelerations that are primarily supported by anaerobic metabolism. Although aerobic contributions to dynamic intermittent sports are significant during recovery, energy demand during these events exceeds the time course of oxidative capacity. VO_2 responses within the heavy (>Lactate Threshold; < Critical Power) and severe (>Critical Power) exercise domains are inadequate in providing the ATP necessary to sustain work (28). Oxidative pathways require ~2-3 minutes to reach near-maximal ATP production after the onset of intense exercise (28). This is due in part to the lack of substrates that enter aerobic pathways at rest (i.e. pyruvate, acetyl CoA) and the number of reactions involved in aerobic metabolism. Therefore, the immediate demand for ATP must be met by stored phosphates and anaerobic processes (phosphagen and glycolytic systems). The anaerobic contribution to exercise performance, or anaerobically attributable power, represents anaerobic capacity (49). The 3 most common approaches to quantify anaerobic capacity are the critical power concept, the maximal accumulated oxygen deficit method (MAOD), and the gross efficiency method. Practitioners are directed towards consideration of the 3-minute all-out test (50) or the modified anaerobic treadmill test (51) for the assessment of anaerobic capacity. Sprint interval training and high-intensity interval training have been shown to improve anaerobic capacity (52).

Muscular strength refers to the external force that can be produced on one occasion by a specific muscle or muscle group(48). Strength can be measured statically or dynamically, with the 1 repetition maximum (1-RM) representing the standard assessment. Multiple repetitions can be used to predict 1-RM in times where measurement of a true 1-RM is discouraged (53). For example, if a practitioner is interested in measuring in-season muscular strength to optimize strength maintenance, a 1-RM may be considered inappropriate, whereas a 5-RM may seem more fitting. Optimal training to improve muscular strength requires heavy loads that result in fatigue within 1-5 repetitions (54, 55).

Muscular endurance represents the muscle's ability to continuously perform successive exertions or repetitions against a submaximal load (48). Muscular endurance can be expressed either as an absolute value (fixed load) or a relative value (%1-RM) (55). For example, the NFL combine assesses muscular endurance using repetitions to failure at a fixed load of 225lb in the bench press. Optimal development of muscular endurance via resistance training is suggested to occur with exercise including greater than 15 repetitions to failure, which improves buffering and oxidative capacity, increased capillarization and mitochondrial density, and enhances enzyme activity (55).

Body Composition represents the diverse phenotypes of athletes, including body weight, size, shape, relative amounts of body fat, fat-free mass, and lean soft tissue mass (56). Practitioners and athletes are aware that relative amounts of body fat and skeletal muscle mass affect athletic performance (57), as increasing amounts of fat mass mechanically and metabolically hinder performance (56) and adversely affect thermoregulation (58). In contrast, increasing amounts of muscle mass contribute to enhanced force production, improving sports performance (56). Therefore, consideration of the relationship between body composition and sport/position-specific performance is essential in the pursuit of peak athletic performance, which may be explored through body composition analysis and benchmarking. Assessments of total body and regional soft tissue mass are related to sport and position-specific athletic performance (56), highlighting the demand for body composition assessment throughout the mesocycles of athletic development. Body composition may be assessed using dual x-ray absorptiometry (DEXA), hydrostatic weighing, air displacement plethysmography, bioelectrical impedance analysis (BIA), and skinfolds. Recently, interest in BIA has increased significantly due to the evaluation of passive bioelectrical characteristics which provide insights into performance, regional tissue hydration and lean mass, muscle asymmetry, cellular function, overall health, injury risk, and recovery from injury (inflammation) (56, 59, 60). Thus, practitioners are encouraged to explore the addition of BIA to traditional body composition assessments.

Flexibility represents the ability of a joint to move through its complete range of motion. Maintenance of an adequate range of motion facilitates movement and may prevent injury. A lack of range of motion results in either compensation patterns that can cause pain/complications, or tissue damage as a result of an activity moving the structure of a joint beyond its range of motion (48). For example, when an athlete's hip flexors are tight or immobile, the pelvis is generally pulled towards a lordotic position that may result in low back pain, which sequentially results in synergistic dominance of the hamstrings as the glute is unable to provide adequate extension, welcoming injury (14). Flexibility and range of motion can be measured with a goniometer. Methods that improve the range of motion include warm-ups, static and dynamic stretching, proprioceptive neuromuscular facilitation, and modalities such as foam rolling (3, 16)

Agility represents perceptual and cognitive responses to stimuli and the resultant change in the position of the body in space with speed and accuracy (3, 48). An important distinction to consider is the difference between change and direction and agility, as most testing and training focus on the ability to perform a change of direction without the perceptual/cognitive response to stimuli. Thus, change of direction ability is foundational to agility. Faster change of direction performances are associated with shorter ground contact times, greater horizontal propulsive and braking forces, and a lower center of mass (61). Practitioners should consider progressing athletes from change of direction training to agility training, by including cognitive responses to stimuli once change of direction performance has improved. Common assessments of change of direction performance include the T-test, hexagon test, pro agility test, and 5-0-5 agility test (3). The utilization of change of direction and agility-specific drills likely provide the best stimulus for producing improvements in athletic performance (62).

Linear Running *Speed* is a product of the frequency and length of strides (63), mathematically indicating that an athlete may increase running speed with an increase in either stride frequency or stride length, without a decrease in the opposing variable. An athlete's stride length depends mostly upon impulse at take-off, the dynamic flexibility of the hips, ground contact time, and morphological characteristics (63). Athletes propel themselves forward only when the foot is in contact with the ground, implying that the training focus for increasing stride length should be placed on the rate of force development, the ability to produce maximum force during high-speed movements, and generating impulse during ground contact (62, 64). Elite-level sprinters consistently demonstrate the application of greater force during shorter ground contact times, while slower sprinters apply less force during extended ground contact times (65). An athlete's stride frequency is a function of ground contact time and cycle time, which depend primarily on the functioning of the nervous system, coordination, and fatigue (63). Interestingly, a more rapid cycle time contributes little to the faster running speeds seen in elite sprinters (65), indicating that interventions designed to improve stride frequency should focus on decreasing ground contact time while maintaining force application.

Balance represents the maintenance of equilibrium while stationary or moving (48). Enhanced balance is positively associated with enhanced athletic performance and negatively associated with lower limb sports injuries (66). Balance testing should include a battery of tests, including both static and functional reaching/hopping to determine overall posture control (67). Interestingly, training that utilized balance boards resulted in improved balance and vertical jump scores, demonstrating that improving balance can improve athletic performance (68).

Coordination (hand-eye and/or foot-eye) represents the ability to use the senses, such as sight and hearing, together with body parts in performing tasks smoothly and accurately (48). The development of the required coordination in athletic performance will likely present itself within the constructs of structured and deliberate sports practice. Although stroboscopic training has increased in popularity as a form of training in which individuals perform a task during intermittent losses of vision, aimed to enhance an athlete's visual, perceptual, and cognitive skills (69). It is astonishing that in most sporting contexts athletes do not regularly participate in visual assessments, as vision is an essential component of sports performance. So much so, success in Major League Baseball can be predicted by visual acuity scores (70). Consideration of annual eye exams is warranted in most sports settings.

Power represents the ability or rate at which an athlete can perform work (48). Horizontal, vertical, and rotational power are required across the spectrum of sporting events. Common measurements of power include vertical jump, broad jump, and throwing a medicine ball. The ballistic performance of vertical jumping depends on both maximal power output and the force-velocity profile of the lower limbs (71). Technological advancements have given rise to velocity-based training as a method of resistance training that enables objective training assessment, development of force-velocity profiles, and exercise prescription (72). An individual's optimal force-velocity profile optimizes jumping performance, while an imbalanced force-velocity profile is associated with lower levels of performance (71). Therefore, training to enhance power should also include stimuli designed to balance the force-velocity profile. This approach has also been used to create force-velocity profiles during sprinting, resulting in optimal loading conditions for enhancing sprint performance (73).

Reaction time represents the time elapsed between stimulation and the beginning of the reaction to it (48). Reaction time is important to measure due to the snapshot it provides of current athletic status, as reaction time is typically prolonged after sport-related concussions (74). An assessment of an athlete's reaction time should be considered in the process of identifying performance-limiting factors, as reaction time can be improved to a small extent with training (75).

PRACTICAL SYNTHESIS & CONCLUSION

Figure 1 displays determinants of athletic performance with a specific focus on modifiable performance-limiting factors. This figure is designed to help practitioners systematically approach the development of training systems, allowing for better detection of the strengths and weaknesses of athletes and the design of more effective comprehensive training interventions. This novel systematic approach has the potential to provide sports practitioners with a vade mecum when creating a training system and should be utilized regularly during training mesocycles.

The main limitation of this approach is that the model provides information as to what specific determinants should be considered in pursuit of peak athletic performance, not precisely how each characteristic can be improved. Future research should address this challenge by applying this model to different sports and presenting the efficacy of developed training systems, further expanding our understanding of comprehensive training systems.

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