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PLANNING

TERMINOLOGY AND DIFFERENTIATION OF TRAINING LOADS

In the following text, based on an abbreviated translation from Leistungssport, Germany, Vol. 26, No. 6, November 1993, the author attempts to improve communication between coaches and scientists by proposing a reconstruction of terminology to be adjusted to training principles and methods based on the required physical performance capacity. The article was originally reprinted from A Collection of European Sports Science Translations, published by the S.A. Sports Institute. Re-printed here with permission from Modern Athlete and Coach.

THE PROBLEM

Everybody interested in the science of training knows that there is a need for a dialogue between theory and practice. The frequent absence of communication between athletes, coaches and sports scientists has been the result of inaccurate terminology and sometimes even contradictions when it comes to the interpretation of training methods. The aim should therefore be to re-construct the methodical training principles, as well as training methods and their characteristics, so that they are based on the required physical capacities.

Such a differentiated new structure is necessary because literature dealing with training sciences refers all conditioning training into four or five basic methods. This allocation is no longer suitable for contemporary specialized training. The training required for all physical capacities is covered in the following basic methods:

- The continuous method
- The interval method
- The repetition method
- The competition and control method.

The aforementioned methods of endurance training were, without close examination, transferred to strength, speed, mobility etc. development. This took place even when the methods did not fit into the accepted practical evidence. At the same time the influences of certain training methods were wrongly evaluated, while others were overlooked because they simply didn't fit into the system.

TRAINING METHODS AND THEIR LOAD COMPONENT

The 'decisive' factors of methodical training have multiple determinations. The decisive levels extend, among others, from the concept, the execution, the organization and the external and internal feedbacks of training to the evaluation and interpretation of it. At the same time the planned procedures to achieve the desired training effects are determined by the arrangement of the training contents and means based on the load components:

- The load volume.
- The load frequency.
- The load intensity.
- The load duration.
- The load density.

These load components allow the determination of the volume, duration, intensity and recoveries for an exercise to be performed (see table 1). The load frequency refers here to daily, weekly and monthly periods and depends largely on an athlete's training state and performance aims.

	STRENGTH LOAD	SPEED LOAD	ENDURANCE LOAD
LOAD VOLUME	Load (kg) in one training unit of an exercise Frequency (f) (repetitions) of an exercise (jumps, throws etc)	Distance (m) of repetitions and series in one training unit Frequency (f) (repetitions) of an exercise	Distance (m,km) of repetitions and series in one training unit of an exercise Duration (hours/week training units/week)
LOAD INTENSITY is determined by	Large impulses (N's) in an exercise Load (kg) % of concentric maximal strength % of isometric maximal strength Impulse quality of an exercise	% of the highest speed value of an exercise Movement speed (m/s) (maximal, sub-maximal, medium) Movement frequency (f) within a time unit	Movement speed (m/s, km/h) Heart rate (HR/min) over a distance % of a certain performance Performance (watt) of an exercise format Type of energy source (maximal)
LOAD DURATION is determined by	Duration (S, min) of an exercise (series) without predetermined frequency (Circuit training)	Time(s) to cover a distance Time(s) for a number of movement repetitions	Time (s, min, h) to cover a distance
LOAD DENSITY is determined by	Recovery times between repetition, series	Recovery times between part-distances, repetitions Certain relationship (for example 1:2, 1:3) between load and recovery durations	Recovery times between part distances, repetition, series Certain relationships (for example 1:2, 1:3) between load and recovery durations

TABLE 1: Operational base of load components (modified from Martin 1991, 1993)

The continuous method is characterized by uninterrupted high volume loads with relatively limited load intensities. The extensive and intensive interval methods are based on a pre-planned alteration between loads and recoveries. The loads are adjusted according to the task. A high volume and medium intensity represents intensive interval training.

Decisive, next to the volume and intensity of the load, is the length of recoveries. In contrast to the repetition method, interval training proceeds from incomplete recoveries. The breaks are consciously adjusted to prevent a complete recovery in order to create fatigue.

The repetition method is also based on a pre-planned alteration of loads and recoveries. However, the aim is for complete or nearly complete recoveries between the repetitions (for example, heart rate < 100/min., subjective feeling, and regulated duration). Intensity, as a rule, is usually quoted as maximal to submaximal and the volume as limited.

The competition and control methods serve mainly for an evaluation of an athlete's state of performance. As a rule, intensity is therefore maximal and the volume in the control method is adjusted to correspond to the demands of a particular event.

TRAINING METHODS IN PRACTICE

The division of training methods and their characteristics in the German sport science literature is certainly useful as a systematization attempt. On the other hand, it complicates concrete planning and conduction of training. Some of the following examples will verify this statement.

Endurance Training

A prerequisite for the use of a recommended load is its operational clarity. Load recommendations for the continuous method should therefore clarify their background. For example, what does "limited" or "60% to 80%" really mean? Is the load value based on the best competition performance, on maximal speed (m/s), on maximal heart rate (HR/min.), or on maximal watt performance?

All these values are, according to the advice and the training aim, employable. Also the pd-values of Conconi, or lactate values, can be used in the determination of intensities. Whatever the chosen value, it will influence the other norms and together with these will have a training effect.

Interval Training

Difficulties in the determination of load norms apply more so to interval training. What do intensity recommendations mean here? Do the intensity recommendations apply to a single load or to a series of loads? How is the incomplete recovery to be interpreted? What differences apply to the determination of intensities for endurance, strength endurance or speed endurance development in interval training?

The situation is even more difficult in the determination of the load density. How is the incomplete recovery determined? The rule for medium and longer single loads in cyclic activities, that recommends a heart rate of 120 to 130/min. before a new load is applied, can only be valid for short anaerobic loads and never for strength endurance training.

The controversial statements on when the recoveries should be incomplete or complete correspond partly to the obviously confusing statements on training aims. In case interval training is supposed to achieve fatigue accumulation from incomplete recoveries, the aim of interval training should be regarded as the development of resistance to fatigue to improve endurance performance capacity.

Several sport scientists (example, Martin 1997, Letzelter 1978, Weiweck 1983, Letzelter 1986, Martin et al 1991), leaning on the theories of Scholich (1965) and Harre (1968), allocate interval training to the role of the development of speed, power, speed strength and explosive strength. However, a closer look at interval training defined as a method with incomplete recoveries in between single loads, reveals that the recoveries in capacities are in practice rather complete. Letzelter (1978) recommends in his "Intensive interval methods III" 3 to 50 minutes recoveries in the development of explosive strength. Obviously this crosses the border of the repetition method.

The border between interval training and continuous training in the development of endurance is also hard to define. This applies to the duration of the load in interval training. Several authors refer here to short, medium and long interval training, corresponding to 15 seconds to 2 minutes, 2 to 8 minutes and 8 to 15 minutes respectively. The type of stimulus in interval training, based on systematical alterations between work and recovery, is overlooked.

Repetition Training

The main problems in converting the information from the literature on load components for practical application occur in the repetition method. Firstly, it is assumed that this method, based on complete or nearly complete recoveries, has the function of avoiding an accumulation of fatigue, or at least delay it as long as possible. This makes it possible to achieve the training aims requiring high loads (for example, the development of speed, explosive strength, reactive strength, technique). Intensive loads can be repeated frequently after full recoveries. The duration of a full recovery cannot be presented in a time unit, because the recovery interval depends upon the previous load. A full recovery after a highly intensive load of a few seconds can be very short (1 to 2 min.), while a maximal load of 3 min. requires a lot longer for complete recovery (15 to 30 min.).

Information on recovery in time units is therefore not useful in practice. Even more confusing in the repetition method are the given intensity ranges (90 to 100%), sub-maximal, maximal. Whilst high intensities are certainly sensible and necessary for many training means, they can only be repeated after a sufficient recovery interval.

Furthermore, loads of considerably lower intensity in higher volumes also have a place in the repetition method (hypertrophy, coordination). For example, load intensities in hypertrophy training can, according to the aim, range from 50 to 80% in employment of a high number of repetitions and full recoveries between the sets.

In Summary: All training exercises performed with alternating loads and complete recoveries correspond to the principles of the repetition method. Extremely high intensities, sometimes regarded as belonging to this method, are unrealistic for certain tasks and therefore not practical. Intensive training exercises are not as decisive in the repetition method as complete recovery intervals in the prevention of fatigue accumulation.

ALTERNATE STRUCTURAL TENDENCIES

Recent sport science literature questions the here criticized traditional division and characteristics of training methods. Trends towards a different approach can already be found in Weineck's work (1983) on training methods for the development of endurance, strength and speed. Martin (1991) writes: "The attempted simplification of the training doctrine that divides all methods into the continuous, interval, repetition, competition and control principles cannot be accepted, in view of the known practical possibilities and the number of components that make up a method."

We recommend as a possible solution to arrange training methods based only on their conditioning or coordinative foundation. Grosser et al have chosen a similar arrangement (table 2).

ENDURANCE	<ul style="list-style-type: none"> • Endurance methods <ul style="list-style-type: none"> – continuous – variable • Interval methods <ul style="list-style-type: none"> – extensive – intensive – repetition method • Competition method • Control method
STRENGTH	<ul style="list-style-type: none"> • Muscular development method • Intra muscular co-ordination methods • Pyramid method • Speed strength methods (2) • Strength endurance methods (3)
SPEED	<ul style="list-style-type: none"> • Repetition method • Intensive interval method
TECHNIQUE TACTICS	<ul style="list-style-type: none"> • Ideomotor method • Movement learning methods

TABLE 2: Training methods (Grosser et al 1986)

Both of the above outlined proposals of structural changes are not convincing for the following reasons:

- The terminology for the different methods is presented at the same comprehension level. The methodical principles (for example, interval and repetition methods) are mixed with concrete methodical measures (for example, strength endurance method, speed-strength method).
- The arrangement of the methods is questionable (for example, the repetition method as a substructure of the interval method).
- The objective is not always correct (for example, the use of intensive interval training for the development of speed).
- The terminology sometimes differs considerably for identifiable methods and is therefore misleading for practical application.

MODIFIED STRUCTURAL CONCEPT

It appears that, because training methods according to their task — development of strength, speed-strength or endurance, have different objectives, it is hardly sensible to arrange the methods based on their typical load components. The repetition method in strength training, for example, has a completely different objective than in endurance training and the load characteristics differ accordingly. From this it appears valid to proceed so that the methodical measures are orientated to practical objectives that are mostly of a complex nature.

The systematic arrangement of training methods in tables 3, 4, 5 can by no means cover the complex training procedures, although it provides an oversight of a large number of combinations and variations. Combined training procedures, mixed formats and modifications occur and become increasingly more important in high performance training. Consequently, the training methods summed up in the table represent only a selection for different training objectives.

The following are some explanatory remarks to the material presented in tables 3,4,5:

The use of the term interval principle can be justified only when we are dealing with endurance, including such complex capacities as strength endurance and speed endurance. The aim is to accumulate fatigue from incomplete recoveries so that the accumulation does not force the reduction of the load volume.

The temporal classification of short, medium and long intervals loads are used with practical training application in mind. The longer the single interval loads, the less valid becomes the term interval because the training effect will be changed.

The concept of strength endurance is based closely on the definition of Buhrie (1985) and Martin et al. (1991) as the capacity to apply strength impulses in a certain time unit without a reduction of the impulse level. We are dealing with resistance to fatigue at an intensity level of 30% below the maximal. This level and duration of the load corresponds predominantly to the anaerobic lactic acid energy supply. Longer and lower strength loads (less than 30% below the maximal) change training into endurance loads under increasing aerobic energy supply and can't be regarded as strength endurance.

Speed endurance is defined as the capacity to keep speed losses minimal in short speed performances of less than 2 min. at maximal or sub-maximal intensity. Grosser (1991) separates 8 to 12 sec. speed performances (submaximal). Martin et al. defines up to 30 sec. maximal intensity performances as sprint endurance and up to 120 sec. sub-maximal intensity performances as speed endurance. We have for practical reasons, eliminated this division.

Decisive in speed endurance and its sub-classifications is the fact that we are dealing with frequency and high intensity endurance performances where the exact limiting factors are not unequivocally explained.

The repetition principle is suitable for several different conditioning training effects. However, it is assumed that the intensity in repetition training is not based exclusively on high and highest possible loads.

PHYSICAL CAPACITY	METHODICAL TRAINING	TRAINING METHODS	CHARACTERISTICS	SPECIFIC TRAINING EFFECTS
ENDURANCE	Continuous principle (without recoveries)	Continuous endurance - extensive - intensive Variable endurance method - fartlek - variable method	Uninterrupted low to medium load intensity high volumes High intensity, medium volumes Unplanned intensity changes Systematic intensity changes	Basic aerobic endurance, regeneration, improved fat metabolism Specific aerobic endurance, improved VO2 max, improved glycogen metabolism Same as in continuous endurance training with additional improvement of anaerobic performance
	Interval principle (incomplete recoveries)	Extensive interval method - short interval loads - medium interval loads - long interval loads	Medium intensity, high volumes - 15s to 1 min. - 1 min. to 2 min.	Specific aerobic and also partly anaerobic endurance, capacity to rearrange energy provision, lactate compensation, extension of VO2 max.
		Intensive interval method - short interval loads - medium repetition - long interval loads	High intensity, medium volumes - 15s to 1 min. - 1 min to 2 min. - over 2 min.	Specific aerobic and also partly anaerobic endurance, capacity to rearrange energy provision, lactate tolerance, activation of glycolytic enzymes
		Repetition method - short repetition loads - medium repetition - long repetition load	High intensity, limited to medium volumes - 15s to 1 min. - 1 min. to 2 min. - over 2 min.	Event specific anaerobic and also partly aerobic endurance, improved energy supply, lactate compensation, lactate tolerance, activation of glycolytic enzymes

TABLE 3: Principles and training methods for basic conditioning, their characteristics and training effect - endurance.

PHYSICAL CAPACITY	METHODOLOGICAL TRAINING	TRAINING METHODS	CHARACTERISTICS	SPECIFIC TRAINING EFFECTS
STRENGTH Maximal Strength	Repetition principle (complete recoveries)	Hypertrophy method	Medium loads (from maximal strength, repetition sets until fatigued, slow to rapid execution)	Development of muscle cross-section
		High and maximal application method	Maximal and sub-maximal loads, few repetitions set, fast and explosive execution	Improvement of inter and intra-muscular co-ordination
		Eccentric method	Supermaximal loads, repetitions sets, slow execution	As in the maximal application method, recruitment of all muscle fibre units
		Isometric method	Maximal static contractions of 5 to 10s	Static muscular strength, muscular development, intra-muscular co-ordination
		Pyramid method - normal pyramid - reduced pyramid - double pyramid	Changing loads and changing repetitions and sets Medium to high loads, medium volumes Limited to medium loads, volumes Medium to high load, medium volumes	As in the hypertrophy and maximal application methods, adjustment to changing
Speed strength Explosive	Repetition principle (complete recoveries)	Speed strength method	Limited loads, medium repetition sets, fast and explosive execution	Improvement of inter and intra muscular innervation, improvement of strength developed speed
		Sport specific speed strength method - analytical - synthetic - variable	Event specific exercises performed fast and explosively execution Competition load Slight additional load Changing load	Improvement of inter and intra muscular innervation with event specific loads, improvement of contraction speed, adjustment to changing innervation
Reactive strength	Repetition principle (complete recoveries)	Plyometric method	Eccentric-concentric strength applications with limited to medium loads (body weight), explosive execution for example, depth jumps, bounding, jumping exercises, reactive throws)	Improvement of inter and intra muscular innervation, development of an optimal stretch-shortening contraction cycle
Strength Endurance	Repetition principle (complete recoveries)	Strength endurance method 1	Medium loads, repetitions sets until fatigued, slow execution, recoveries	Capacity to resist fatigue in anaerobic strength performances, improvement of anaerobic energy supply, lactate tolerance
	Interval principle (incomplete recoveries)	Strength endurance method II	Limited loads, large number of repetitions, sets until fatigued, slow execution, recoveries between sets about 1 min.	As in strength endurance method 1, recovery I, recovery capacity
Explosive strength endurance	Repetition principle Interval principles	Sport specific strength endurance method	Optimal event specific force application until force application reduces, for example, jumps, throws, hits	As in strength endurance methods I and II, maintenance of force application, delayed programming fatigue

TABLE 4: Principles and training methods for basic conditioning, their characteristics and training effect - strength.

PHYSICAL CAPACITY	METHODICAL TRAINING	TRAINING METHODS	CHARACTERISTICS	SPECIFIC TRAINING EFFECTS
SPEED	Repetition principle (complete recoveries)	Maximal contraction speed method	Highest intensity, short load up to 7s	Improvement of innervation and relaxation capacities under anaerobic speed loads
		Innervation method, co-ordination method	Co-ordination exercises for example: - downhill - towed runs - assisted jumps	Improvement of innervation and relaxation capacities in changing co-ordination demands and variations
Speed strength	Repetition principle (complete recoveries)	Speed strength method, reactive strength method	As in speed strength and reactive strength methods	As in speed strength and reactive strength methods
		Overloading method	Resisting conditions, for example: - uphill running - exercises with additional loads - exercises against pulling resistance	Improvement of movement speed under increased resistances, improvement of inter and intra muscular innervation
Speed endurance	Repetition and interval principles	Speed endurance method	Intensive speed exercises until fatigue speed	Development of fatigue resistance in speed performances, delaying programming fatigue, improvement of anaerobic energy supply, lactate tolerance
		Overdistance method	Intensive overdistance loads, recoveries reductions according to state of training	
Reaction speed	Repetition principle (complete recoveries)	Reaction method	Reaction to different optical and acoustic signals	Improvement of reaction and anticipation times
		Anticipation method	Reaction to movable objectives complex reactions to ball, opponent etc.	
MOBILITY	Repetition principle (complete recoveries)	Dynamic stretching method	Dynamic (springy) stretching	Improvement of active and passive mobility, avoidance of muscular imbalance, injury prevention
		Static stretching methods - stretching method I - stretching method II (for example, AED, PNF)	Static (holding) stretching	
ALL PHYSICAL CAPACITIES	Competition principle	Competition and control method	Competition performances, loads similar to competition demands	Complex event specific performance capacity, exploitation of the functional potential

TABLE 5: Principles and training methods for basic conditioning, their characteristics and training effect - speed and mobility.



PHYSIOLOGY

PHYSIOLOGICAL TRAINING PRINCIPLES ARE OFTEN INACCURATE

This review article critically evaluates several physiological models (i.e., explanations) that are supposed to account for exercise responses and improvements. Such models are variously used as the theoretical bases for structuring training programs for athletes. A central theme of the review is that contemporary physiology looks at explanations for responding rather than the accurate prediction of performance improvements. The former is relatively secure from critical evaluation whereas the latter is difficult to research and has an inherent possibility of failure.

A second suggestion is that contemporary physiologists have forgotten the history of the discipline. Many informative, substantive, and valuable principles of exercise response were discovered in the first part of the twentieth century but have gradually have fallen out of the common literature. That omission is one of the reasons that contribute to modern theories of exercise physiology being incomplete and inaccurate.

Research Weaknesses

The accurate measurement of exercise responses in the field has been subverted by laboratory testing. The author offers three reasons why this has occurred.

1. The variables influencing human performance are not easily controlled. A field setting exacerbates that difficulty. This has led to the situation where laboratory measurements are used to infer performance characteristics in the field (e.g., a change in VO_{2max} is used to infer the likelihood of an endurance performance change).
2. There is a dearth of tools to measure accurately human performance in the laboratory. If sports performance cannot be measured frequently with a high degree of precision in the laboratory, then training-induced changes in sports performance are not quantifiable. Direct, accurate testing is rarely possible. Consequently, physiological surrogates (e.g., VO_{2peak} , VO_2) are used to predict changes in performance.

"... most training studies ... have measured the physiological and biochemical responses of the human to training and have paid less attention (i) to the extent to which human exercise performance is altered by different training programs and (ii) to the specific physiological adaptations which explain training induced changes in athletic performance." (p. 124)

3. An important weakness in current exercise physiology is a lack of certain knowledge of the precise factors that determine fatigue and hence, limit performance in different types of exercise under a range of environmental conditions. This is largely due to researchers and teachers advocating only one specific incomplete model of exercise physiology that does not explain performance under all conditions.

The review contemplates five exercise physiology models used popularly to explain and guide physical conditioning programs.

1. The Cardiovascular/anaerobic Model

In maximal exercise, this model holds that endurance performance is determined by the capacity of the heart to pump large volumes of blood and oxygen to muscles. That facilitates muscles achieving higher work rates ("*cardiovascular fitness*") before outstripping the available oxygen supply ("*anaerobiosis*"). The capacity of the muscles to use fat as fuel ("*aerobic lipolysis*") is also increased. This is currently the most popular model for guiding the structure of training programs.

An increase in coronary blood flow that is inherent in this model is largely overlooked. However, the pumping capacity of the heart is restricted and limits oxygen utilization. Since that is so, the heart itself will be the first organ affected by the postulated oxygen deficiency. A. V. Hill's pioneering work has been incorrectly interpreted and an error perpetuated. Hill's actual interpretation of the fatigue that develops during maximal exercise was:

"Certain it is that the capacity of the body for muscular exercise depends largely, if not mainly, on the capacity and output of the heart. It would obviously be very dangerous for the organ to be able, as the skeletal muscle is able, to exhaust itself very completely and rapidly, to take exercise far in excess of its capacity for recovery . . . When the oxygen supply becomes inadequate, it is probable that the heart rapidly begins to diminish its output, so avoiding exhaustion . . ." (Hill et al., 1924)

The heart is a muscle that is subject to the same functional constraints as skeletal muscle -- it needs oxygen to operate. The cardiovascular/anaerobic model ignores the role of the heart and assumes that all muscles fatigue at the same rate, both heart and skeletal. There must be some form of a central "governor" that stops the heart from reaching dangerous levels of fatigue. No such mechanism has been discovered because no one has looked for it.

Peak blood lactate, maximum heart rate, and cardiac output all fall with increases in altitude. At altitude, exercise terminates when exercising muscles are contracting in fully aerobic conditions. Thus, this model is unsatisfactory when it proposes the delivery of an adequate oxygen supply to exercising muscles is the cardinal priority during exercise. Some unexplained mechanism must exist that prevents the heart from becoming anaerobic during maximal exercise at any altitude. Neither skeletal nor cardiac muscles show any evidence for anaerobic metabolism at altitude.

The model is inconsistent when submaximal work is compared to maximal work. Similar function in maximal work must also exist in submaximal work, but at the lesser level, oxygen transport cannot be limiting. For example, a superior capacity for oxygen consumption during maximum exercise does not explain the manifest superiority of Kenyan runners during more prolonged submaximal exercise. Black runners have been shown to run substantially faster at all distances beyond 5 km despite VO₂max values that are similar to middle-distance runners. What they did exhibit was a capability to sustain a substantially higher proportion of their VO₂max when racing. They have superior fatigue resistance rather than aerobic capacity [%VO₂max is a valid measure of fatigue resistance.] A VO₂max test does not measure all the physiological variables determining success during more prolonged exercise.

"In summary, there are serious theoretical flaws in the proposed cardiovascular/anaerobic mode of exercise physiology and athletic performance, . . . not least because the model predicts that a "plateau" in cardiac output must develop before skeletal muscle anaerobiosis can begin to occur. But any "plateau" in cardiac output requires that myocardial ischaemia be present either to cause that plateau (according to the theory that anaerobiosis limits muscle function) or as a result of it, as the cardiac output determines both coronary and skeletal muscle blood flow. As myocardial ischaemia has never been shown to develop during maximal exercise in healthy humans, so it would seem unlikely that skeletal muscle anaerobiosis can develop during progressive exercise to exhaustion . . . Rather, it would seem that "fatigue" during maximal exercise of short duration is part of a regulated neural process that prevents the development of myocardial ischaemia during maximal exercise." (p. 132)

Implications. Skeletal muscles do not develop anaerobiosis and form the effect that limits exercise. Some governor that protects the human from destructive fatigue level appears to exist. The functioning of the heart seems to be the important factor in any maximum exercise, and should be the emphasis of training programs.

2. The Energy Supply/Energy Depletion Model

This energy supply model predicts that performance in events of different duration is determined by the capacity to produce energy (ATP) by the separate metabolic pathways including the phosphagens, oxygen-independent glycolysis, aerobic glycolysis, and aerobic lipolysis. Superior performance is explained by a greater capacity to generate ATP in the specific metabolic pathways associated with an activity. For example, a common explanation is that a sprinter has a greater capacity to generate ATP from intramuscular phosphagen stores and oxygen-independent glycolysis, as opposed to a marathon runner who has a superior capacity to oxidize fat (*aerobic lipolysis*). Its basic tenet is that exercise must cease when ATP depletion occurs.

The status of this model's hypotheses is uncertain, as insufficient substantive research has been conducted. To validate this model's reasoning, the following have to be demonstrated.

- The different metabolic pathway capacities need to be causally related to different events.
- Specific metabolic pathways adapt specifically to different forms of training.
- Adaptations alone explain different performances that result from training exercises of different duration.

Research has shown the following, each of which contradicts the implications of this model.

- ATP concentrations in "exhausted" muscles rarely drop below 60% of resting values.

- High-energy phosphates do not participate in fatigue, but other factors reduce the use rate of ATP before ATP becomes limiting.
- There is a wide range of muscle pH concentrations reached at exhaustion (uniform acidosis is not exhibited across muscles).
- ATP demand by contracting muscles never exceeds the maximum rate of ATP supply.
- Muscle recovery is related to recovery of muscle phosphocreatine concentrations and unrelated to muscle pH concentrations.

Some peripheral *governor* needs to exist to account for these observations because acidosis does not play a direct role in fatigue in maximal exercise. Exercise terminates for reasons other than muscular *lactacidosis*.

Implication. Exercise is not limited by muscles achieving any critical level of acidosis although the availability of intramuscular phosphagen stores is. The contribution of neural factors that intervene with maximum peripheral muscular exercise has to be considered.

The energy depletion model is specific to exercises lasting longer than two hours. It holds that depletion of endogenous carbohydrate (CHO) stores limits the ability to perform long term exercise.

Much research to support this model has been conducted with inadequate or absent controls. Recently, better experimental designs have been used and placebo effects, as well as less consistent results, have been recorded. Additionally, the phenomenon of CHO-loading is not as evident in women as it is in men (it is hard to grasp why there would be a gender difference in biochemical function).

It is virtually impossible to prove conclusively that muscle glycogen depletion alone limits prolonged exercise performance because so many other factors occur concurrently. To support this model, future research has to show that neural factors are not involved (they seem to be involved in the previous two models).

- It is unclear how an inability to produce ATP at sufficiently high rates from one fuel source can explain this form of fatigue, given that ATP concentrations in muscles remain high in all forms of exhaustion.
- Further contradictory studies have shown that individuals ceased performing in the fourth hour of exercise when their muscle glycogen concentrations were the same as they were at the end of the first hour of exercising.
- Huge increases in muscle glycogen concentrations at the start of exercise only have a minimal impact on performance improvement in some subjects.
- It has not been shown that training improves endurance performance exclusively by increasing body carbohydrate stores and by delaying the onset of carbohydrate depletion.
- Very prolonged exercises (e.g., Ironman triathlons, 100-mile races) oxidize amounts of CHO in volumes that far exceed those existing in the body, without much detriment to performance in their later stages.

The human body is limited in its capacity to store CHO. High rates of CHO oxidation are required to sustain high rates of energy expenditure. Studies of very prolonged exercise show that rates of CHO oxidation remain high in athletes who ingest appropriate CHO during exercise. Because both muscle and liver glycogen depletion occur in fatigue, it is commonly assumed there is a direct causal relationship between muscle glycogen depletion and the development of fatigue in prolonged exercise. However, the relationship might not be causal under all circumstances. There is a logical impasse because any energy depletion model predicts that exercise must terminate when muscle ATP depletion occurs (leading to muscle rigor). Other factors must be involved in causing fatigue in prolonged exercise.

A popular explanation for "*sparing*" CHO is that with training, the ability to oxidize fats improves and this extends and improves performance without requiring higher CHO utilization. However, that explanation is still inadequate because ultimately it proposes that ATP depletion limits exercise, something that does not occur. This model is too simple to explain the physiology of prolonged exercise.

Implication. The CHO-depletion model does not adequately explain the response to prolonged exercise because at the end of the metabolic chain, ATP is not depleted. Some other reason has to exist for exercising to cease.

This and the previous model "are based on the assumption that it is either the delivery of substrate either in blood (oxygen) or via the glycolytic and oxidative pathways (ATP) that limits exercise performance. The steps of (ii)logic that have influenced these assumptions have been described . . . It remains difficult to prove whether or no either of these models is correct. Yet both continue to dominate, perhaps subconsciously, research and teaching in the exercise sciences, often to the exclusion of competing possibilities." (p. 137)

3. The Muscle Recruitment (Central Fatigue)/Muscle Power Model

The fourth model has two parts that imply it is not the rate of supply of substrate (oxygen or fuel) to muscle that limits performance, but rather the processes involved in skeletal muscle recruitment, excitation, and contraction. The concept of central neural fatigue is invoked.

For the muscle recruitment model, the evidence is sufficiently persuasive to believe that central nervous system fatigue contributes to diminished performance in prolonged exercise, at altitude, and in the heat. In no study observing this phenomenon, is there evidence of anaerobiosis or energy depletion. This model also proposes there is a progressive peripheral fatigue for which the central nervous system makes an appropriate adjustment.

The central neural model does not specify important physiological mechanisms to account for fatigue.

Professor Noakes has argued elsewhere that a reduced central activation of exercising muscles is a protective mechanism. It prevents the following states.

- Myocardial ischaemia.
- Muscle ATP depletion.
- Myocardial ischaemia or cerebral hypoxia at altitude.
- A fall in blood pressure.
- Heatstroke.
- Glucopaenic brain damage during states of hypoglycaemia.

The muscle power model proposes that muscle contractile capacity, the ability to generate force, is not the same in the muscles of all humans. Superior athletes have a superior capacity to generate force. Very little has been researched on this alternative. David Costill reported that endurance training reduces skeletal muscle contractility, which shows that muscle contractility is not an immutable characteristic of the different muscle fiber types.

"In summary, these two sub-models . . . predict that changes in exercise performance may result from increased skeletal muscle recruitment resulting from enhanced central neural drive, or from increased muscle contractile function resulting from biochemical adaptations in muscle that increase either force production or rate of sarcomere shortening, or both." (p. 139)

Implication. Performance increases resulting from this model would only occur within the limits of cardiovascular function within the specific activity.

4. The Biomechanical Model

Performance prediction is based on the greater the muscle's capacity to act as a spring, the less torque it must produce and hence, the more efficient it is. An improvement in performance stems from an increase in elastic muscle efficiency. That efficiency results from slowing the:

- Rate of accumulation of metabolites that cause fatigue, and
- The rate of rise in body temperature.

Reaching a core temperature that prevents continuing exercise is delayed.

This model is in direct contrast to the cardiovascular/anaerobic model, which predicts that superior performance during prolonged exercise results from an increased oxygen delivery to muscle and an increased rate of energy, resulting in increased heat production. A more logical assumption would be to reduce the rate of oxygen consumption and heat production by increasing the economy of movement.

Two factors that reduce heat production are small size and superior running economy. The more economical the athlete, the faster he/she will be able to run before reaching a limiting body temperature. Most training studies show that improvements in running/movement economy result from practice. Thus, being more economical, rather than having a higher VO₂max, appears to be a more logical approach for explaining enhanced endurance performance.

A second component of this model stems from observations that repeated high velocity, short duration eccentric muscle contractions, as occur during running, induce a specific form of fatigue that lasts for a considerable time after cessation of the fatiguing activity. Characteristics of that fatigue are reduced contractile capacity, reduced tolerance for

muscle stretch, and a delayed transfer from muscle stretch to muscle shortening in the stretch-shortening cycle. These result in the duration of a movement cycle being extended. Since these abnormalities last for several days they cannot be explained by oxygen or substrate delivery models.

In summary, the biomechanical model predicts that superior performance, especially in a weight-bearing activity like running, may be influenced by the capacity of the muscles to act as elastic energy return systems.

Implication. This model will demand that recovery be given as much emphasis as overload in training so that muscle function is preserved as long as possible, thereby facilitating the greatest volume of effective training.

5. The Psychological/motivational Model

Any demonstration of an ergogenic effect of any placebo intervention on exercise would prove this model contributes, at least in part, to athletic performance. In the field of physiology, this model is rarely considered. It does have some credibility in sport psychology, as well as emerging support from CHO-loading studies that are beginning to show a placebo effect.

Implication. The structure and content of an athlete's thinking could have an effect on the quality of performance.

Conclusions

" . . . until the factors determining both fatigue and athletic performance are established definitely, it remains difficult to define which training adaptations are the most important for enhancing athletic performance, or how training should be structured to maximize those adaptations." (p. 141)

Many findings are incompatible with the predictions of these models. The traditional tenets of physiology should be challenged until universal predictive validity is established.

New interpretations of training structures and content are warranted. The limited reasons and implications from the restrictive models described in this review will not result in the best form of training. The following are implied [training adaptations are considered to be responses that will transfer to competitive performances].

- The use of laboratory measurements, which are only partially related to laboratory performance, are useless for predicting competitive performances.
- Training programs based on oxygen and substrate supply theories, are likely to result in incorrect stimulation and will not yield maximal fitness adaptation for a specific sport.
- Training that emphasizes the reaction of muscles in the replicated activities of the sport is likely to produce beneficial fitness adaptation. [It should be noted that training with auxiliary activities, such as weight training, will not produce adaptations that generalize to competitive performances.]
- The physiological responses to complicated sporting activities are likely to be caused by a complicated set of physiological processes. Limiting training "theory" to one incomplete physiological model will not result in maximal fitness adaptation for a specific sport.
- It is likely that training programs developed by incorporating principles from psychology, biomechanics, and physiology will stimulate the best training adaptations for a particular sport.