



12

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PHYSIOLOGY

12

The following brief outline provides basic information concerning physiology for sport and fitness and refers to:

- muscle
- energy systems
- strength
- flexibility
- body composition
- training principles

A. Muscle

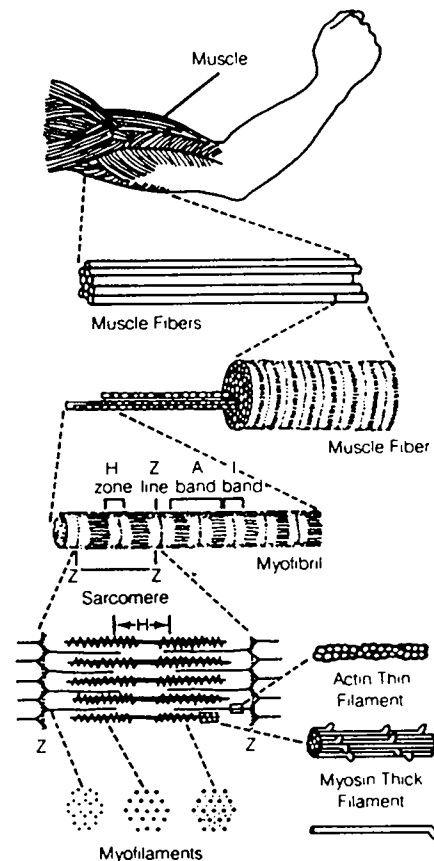
Structure of the Skeletal Muscle

Skeletal muscle usually refers to a number of muscle bundles bound together by connective tissue. Each bundle is comprised of thousands of individual muscle cells or fibres. Each fibre contains myofibrils which occupy 80% of fibre volume and vary in number from several hundred to several thousand per fibre depending on the fibre's diameter. The myofibrils consist of smaller filaments arranged in repeated patterns along the length of the fibril. Each myofibril is divided along its length into sarcomeres which are the functional units of the contractile system. Each sarcomere contains two types of filaments: 1) thick filaments made of the contractile protein myosin and 2) thin filaments made of the contractile protein actin.

Sliding Filament Theory

When a skeletal muscle fibre shortens or contracts, the lengths of the thick and thin filaments do not change. However, the actin filaments slide past the myosin filaments by cross-bridge attachments between the myosin and actin. The length of the sarcomere does change due to the inward movement of the actin. The globular end of myosin has an active enzymatic site that catalyzes the breakdown of adenosine triphosphate (ATP) and inorganic phosphate, thus releasing the chemical energy stored in ATP needed for the cross-bridge movement. ATP is also needed to break the link of myosin and actin at the end of a cycle allowing it to be repeated.

Figure 12.1 Levels of fibrillar organisation within a skeletal muscle. (From Vander, AJ Sherman, JH, & Luciano, DS. (1980). Human Physiology, McGraw-Hill Inc, New York, p. 212.)





Types of Skeletal Muscle Fibres

Not all myosin molecules are identical and therefore there are three different types of skeletal muscle fibres that can be identified based on their speed of contraction and capacity to split ATP.

“Slow twitch-resistant to fatigue” fibres

- low myosin-ATPase activity therefore slow speed of contraction
- high oxidative capacity and nutrient supply
- many mitochondria
- increased capillary/fibre ratio
- ATP production by oxidative phosphorylation
- low glycolytic enzyme activity
- net result: fatigue resistant

“Fast twitch-resistant to fatigue” fibres

- high myosin-ATPase activity therefore rapid speed of contraction
- moderate oxidative capacity and nutrient supply
- moderate number of mitochondria
- ATP production by oxidative phosphorylation
- intermediate glycolytic enzyme activity
- net result: fatigue after long periods of time in a contracted state

“Fast twitch-fatiguable” fibres

- high myosin-ATPase activity therefore rapid speed of contraction
- low oxidative capacity and low nutrient supply
- few mitochondria
- ATP production by anaerobic glycolysis
- high glycolytic enzyme activity
- net result: quickly fatigue as they exhaust glycogen supply and low nutrient supply cannot quickly replenish glucose

A few muscles may contain predominantly one type of fibre. However, most muscles contain a mixture of the three types of fibres although in varying proportions. This is significant as skeletal muscle must perform a variety of functions in different locations in the body.





B. Aerobic and Anaerobic Energy Systems

Physical activity requires energy and energy in the muscle is in the form of adenosine triphosphate (ATP). There are three sources of ATP: i) stored creatine phosphate (CP) and ATP in muscle, ii) ATP generated by oxidative phosphorylation in the mitochondria and iii) substrate phosphorylation during glycolysis.

At the start of contraction, creatine phosphate (CP) provides the fastest means for replacing ATP; however, CP stores are limited to providing energy for only a few seconds. As muscle activity continues or increases, moderate rates of ATP generation can occur using fatty acids as the major nutrient source through the process of oxidative phosphorylation. As ATP breakdown becomes very rapid with intense exercise, glycolysis contributes a significant amount of ATP in the muscle.

All activities can be classified on the basis of the contribution of the energy system or systems that are involved. A general estimation of the ability of the athlete to generate energy from each of the three systems is possible by simple exercise tests (see later). A further discussion of the use of glycogen by muscles during exercise is presented in Unit 13 - Nutrition.

Aerobic Power

Aerobic power ($\dot{V}O_2$ max) refers to the rate of aerobic energy used and is often defined as the volume (\dot{V}) of oxygen (O_2) that can be consumed per minute during maximal exercise. It is often expressed as millilitres (mls) of oxygen (O_2) per kilogram (kg) body weight to allow comparisons between different athletes. Aerobic power is important for both intermittent or sustained endurance activity. When the activity exceeds three minutes in duration, the importance of this system for energy production increases rapidly (see Figure 12.2).

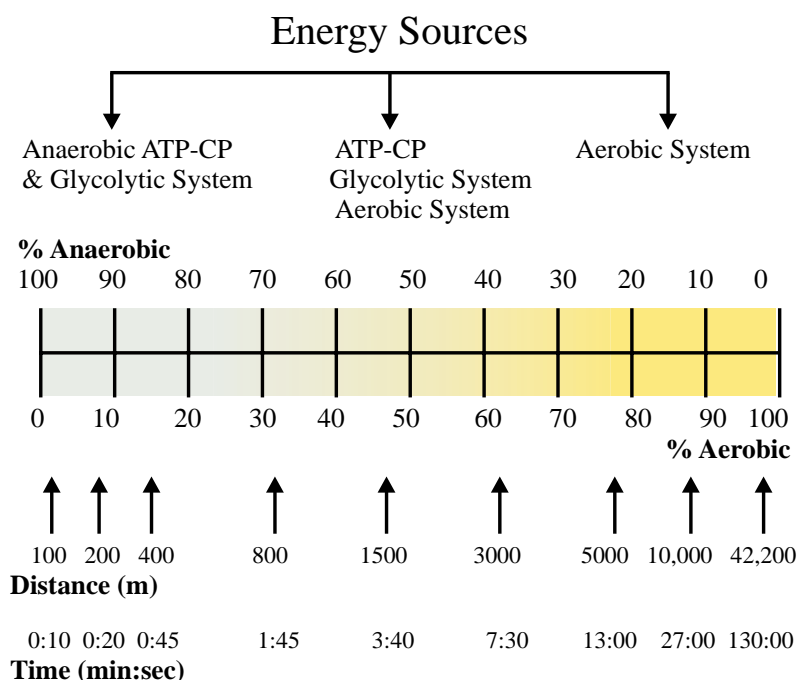


Figure 12.2 The primary energy sources for events of different duration. (From Van Handel, P & Puhl, J. (1983). Sports Physiology - Testing the Athlete. Clinics in Sports Medicine, 2(1): 23.



Although high aerobic power, as expressed by a high $\dot{V}O_2$ max value, is essential for successful performance in endurance events, it is not possible to predict success in performance using these values alone. The “anaerobic threshold”, which is the exercise intensity when the blood lactate begins to rise, is a better predictor of success in endurance events. Well-trained aerobic athletes have anaerobic thresholds at greater than 90% $\dot{V}O_2$ max. This threshold represents the upper limit of energy supply from predominantly aerobic sources.

Aerobic training stimulates improvement in cardiac output, increased blood volume, and increased extraction of arterial oxygen by the muscle, resulting in greater aerobic capacity. A summary of the physiological profile of an aerobically trained athlete in comparison to an untrained individual is presented in Table 12.1.

Table 12.1 Physiological profile of untrained and trained persons.

VARIABLE	UNTRAINED	TRAINED
Weight (kg)	75	68
Percent fat (%)	10-18	5-10
Resting heart rate (b/min)	70-80	40-60
Max heart rate (b/min)	180-210	175-195
$\dot{V}O_2$ max ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	40-50	55-85
Max cardiac output ($\text{l} \cdot \text{min}^{-1}$)	15-25	25-32
Max minute ventilation ($\text{l} \cdot \text{min}^{-1}$)	120-150	145-210
Skeletal muscle:		increase with training
myoglobin content	--	
number & size of mitochondria	--	
aerobic enzyme activity	--	
Blood volume	--	

Athletes with greater aerobic power will recover from intense, anaerobic exercise more quickly than those with lower capabilities. Aerobic power is largely determined by genetics. It can be improved 20-25% with training.

To accurately test aerobic power, sophisticated laboratory equipment is necessary. Although it is possible to predict $\dot{V}O_2$ max values from submaximal tests, the error rate (15%) may make this test inappropriate for elite athletes. Care must be taken to test the athlete on the type of ergometer that reflects their sport, eg., treadmill for running sports, cycle ergometer for cyclists, rowing ergometer for oarsmen. For these tests, an exercise physiologist with oxygen and carbon dioxide gas analysers and a collection system for expired air are necessary.

One simple field test for estimating aerobic power involves measurement of the distance run in 12 min (see Table 12.2). The distance covered in 12 min gives an estimate of the fitness of the participant.

Table 12.2 Twelve minute running test.

FEMMES Groupes d'âge				
CATEGORIE DE CONDITION PHYSIQUE	moins de 30 ans	30 - 39 ans	40 - 49 ans	plus de 49 ans
Km courus				
mauvaise	< 1.52	< 1.36	< 1.20	< 1.04
médiocre	1.52 - 18.2	1.36 - 1.66	1.20 - 1.50	1.04 - 1.34
moyenne	1.84 - 2.14	1.68 - 1.98	1.52 - 1.82	1.36 - 1.66
bonne	2.16 - 2.62	2.00 - 2.46	1.84 - 2.30	1.68 - 2.14
excellente	> 2.64	> 2.48	> 2.32	> 2.16
HOMMES Groupes d'âge				
CATEGORIE DE CONDITION PHYSIQUE	moins de 30 ans	30 - 39 ans	40 - 49 ans	plus de 49 ans
Km courus				
mauvaise	< 1.52	< 1.36	< 1.20	< 1.04
médiocre	1.60 - 1.98	1.52 - 1.82	1.36 - 1.66	1.28 - 1.58
moyenne	2.00 - 2.38	1.84 - 2.2	1.68 - 2.06	1.60 - 1.98
bonne	2.40 - 2.78	2.24 - 2.62	2.08 - 2.46	2.00 - 2.38
excellente	> 2.80	> 2.64	> 2.48	> 2.40

Anaerobic Power

Anaerobic power is the maximal ability of the two anaerobic energy systems, adenosine triphosphate plus phosphocreatine (ATP + PC) and glycolysis, to produce energy. Adenosine triphosphate and phosphocreatine are high energy compounds stored in the muscle cell in limited amounts. They provide energy for high intensity exercise but can only sustain this activity for 6-8 seconds. Glycolysis provides energy for intense activity lasting 60-90 seconds. Lactate and hydrogen ions are produced through anaerobic glycolysis and as they increase, contribute to the fatigue of the muscle.

Anaerobic power is essential for success in events requiring intense effort over a short period of time. The measurement of anaerobic capacity is difficult although several tests have been created to attempt this. One of the most common is to measure blood lactate after exhaustive exercise to estimate anaerobic



energy release. The presence of lactate certainly indicates the occurrence of glycolysis, but the quantity of lactate present in blood probably does not accurately represent the quantity produced by muscle. There are three reasons for this: when lactate leaves the muscle, some is metabolized; there may be a different variability of dilution space for lactate; and it is difficult to determine when or if equilibrium occurs.

Another test is to measure the oxygen deficit following exercise until $\dot{V}O_2$ returns to a normal basal value. The difficulties here include the fact that more energy is needed to synthesize glycogen from lactate than is freed when glycogen is metabolized to lactate; some lactate is oxidized during exercise and this will not be reflected in post-exercise oxygen consumption; and factors other than lactate, after exhaustive exercise, result in an increase in oxygen consumption.

Oxygen deficit calculations for short-term sub-maximal work may provide a reasonably accurate estimate of anaerobic work. For maximal work of short duration (ie. 1-10 min), oxygen deficit calculations may be useful if the energy cost of the work can be calculated. To do this for exhaustive work, one must be able to estimate the energy expenditure by identifying the mechanical efficiency of a particular activity, or by knowing the relationship between work intensity and oxygen uptake.

Tests utilizing all-out effort for short duration (ie. 0-30 sec) may not be of long enough duration to fully exhaust all anaerobic energy resources, particularly that amount contributed by glycolysis. In the first few seconds of intense exercise, ATP concentrations are reduced 2% and CP concentrations by 80%. These alactacid components account for approximately 25-30% of the available anaerobic energy in untrained or trained individuals. Glycolysis (lactacid component) contributes 60% of anaerobically derived energy in untrained individuals and 70% in trained.

Much of the training to improve the anaerobic energy capacity of muscle involves high intensity exercises of 40-60 sec duration repeated several times, with rest intervals only long enough to allow the next exercise piece to be completed. This training improves the activity of glycolytic enzymes, buffer capacity and transport of lactate away from exercising muscles. However, endurance training that improves aerobic capacity (eg. improves muscle blood flow and capillarization, and increases haemoglobin, myoglobin and oxidative enzymes) helps improve anaerobic capacity by improving the transport and oxidation of lactate.

C. Strength

Strength is a universal requirement for competitive athletes and this component is usually reflected in their training programs. There are four types of muscular contractions:

1. **Isometric contraction** - tension increases while the muscle length remains constant. Strength increase occurs mainly at the joint angle where the tension is applied.
2. **Concentric contraction** - tension increases as the muscle shortens. This is the standard method of weight training for most athletes.
3. **Eccentric contraction** - tension increases as the muscle lengthens. Strength gains may be greater than for other types of strength training. Muscle soreness is an increased risk. Longer recovery times between exercises are necessary.
4. **Isokinetic contraction** - concentric contraction in which the speed of movement of a joint is maintained at a constant velocity. The tension produced is variable and depends on the velocity

and joint angle. This type of training requires special equipment, such as the Cybex isokinetic dynamometer, but has been responsible for strength gains greater than those achieved from resistance (concentric) or isometric methods.

Strength training can result in significant increases in the ability to develop muscle force. As many sports have power (force x acceleration) as a primary ingredient, training of the speed of contraction is also necessary.

Strength training should be as specific as possible in terms of the type of contraction, speed of contraction, the muscle recruited and the pattern of movement. Strengthening of muscles not directly required in the activity may be a liability.

Maintenance of strength and muscular endurance following a significant strength training period may be accomplished by one or two appropriate work-outs per week. Complete cessation of training will not affect strength for four weeks.

Maximum strength of a muscle group may be assessed in the training room by determining the maximal weight that can be lifted for three full repetitions. Proper warm-up and supervision are required. Alternatively, strain gauges can record isometric strength changes at different joint angles or isokinetic equipment can objectively measure tension. The KinCom apparatus can estimate eccentric as well as isokinetic strength.

Additional discussion of strength training is outlined in Unit 11 B b. Strengthening.



D. Flexibility

The ability of the joint to move through a complete range of motion is important for injury prevention and performance. Although little research has been done on flexibility, most coaches and athletes believe flexibility exercises must form an essential component of the training programs. An additional discussion of flexibility is outlined in Unit 11 B c. - Flexibility.

The following guidelines, with regards to flexibility, should be noted:

- begin an exercise session with light rhythmic exercise and then stretch. The muscle temperature is higher and the muscle/tendon unit can be stretched farther
- precede a passive stretch with an isometric contraction to improve flexibility (proprioceptive neuromuscular facilitation technique)
- passive stretches held for 30-45 sec form the basis of any flexibility program
- stretches must not be painful
- to be successful, stretching must be done on a regular basis, preferably daily and should precede and follow each exercise session
- ballistic or “bounce” stretching must be avoided, as it may cause injury to the soft tissues



E. Body Composition and Anthropometry

The body is composed of:

- lean body mass (fat-free weight): all of the body's non-fat tissues, including bone, water, organs and teeth
- body fat: the essential and non-essential lipid stores

Body composition is an important consideration for many athletes. For those individuals involved in sports with weight categories (eg. wrestling, weight-lifting), body weight must be observed and planned. Unfortunately, the practice of "making weight" has resulted in many serious abuses, both with drugs and dietary manipulation (see Unit 13, section E 3 "Making Weight" for Weight Class Sports).

Anthropometric measures that have been useful in studying athletes include determination of body mass, lengths (eg. height, proximal and distal upper arm, forearm, thigh and calf), girths (eg. acromion, upper arm relaxed, forearm, subgluteal, mid-thigh, etc), skinfolds, estimates of total muscle mass and segmented volumes. Somatotyping the body into three component ratings (endomorph, mesomorph, ectomorph) provides a good single description for the classification of the shape of the body.

Measurement of Body Composition

There are many methods that have been devised to estimate body composition.

Underwater weighing (hydrostatic, densimetry) is considered the most accurate measure of body fat and serves as the standard for other techniques. It involves weighing the athlete while underwater, correcting for air that is left in the lungs following a maximal exhalation and using equations to estimate body fat. The principle is that a person with larger fat stores is more buoyant in the water and therefore weighs less. This technique requires a large tank or pool and has an error of approximately 2.5%. Other methods for assessing body composition are available: potassium-40, total body water, inert gas absorption, nuclear magnetic resonance, computerized tomography (CT) and electrical impedance. Some show promise but all are expensive and CT scanning exposes the subject to radiation.

Skinfold measurement is the most popular method of assessing body fat. It is quick and inexpensive but may be subject to error in measurement technique if more than one technician is used. However, by using multiple measurements taken by a single experienced observer, the technique is useful in monitoring change in athletes over time.

The technique for obtaining skinfold measurements is as follows. A skinfold caliper (eg. Harpenden) is used to obtain a measure of a double thickness of skin and subcutaneous tissue, including fat, without including any underlying muscle tissue (Figure 12.3). A double layer of skin and subcutaneous tissue is grasped with the thumb and forefinger, the fold being large enough to get a complete double layer, but not so large to include so much skin and fat that excessive tension results at the fingertips. The fold of skin and fat is held loosely between the fingers while the measurement is being made. The faces of the caliper are applied about 1 cm from the thumb and closer to the body than the fingers. The reading on the dial is taken after applying full spring pressure on the instrument by a complete release of the grip on the trigger lever. The measurement is taken to the nearest 0.1 mm and is recorded on the following form.



Figure 12.3 Skinfold measurement using calipers.

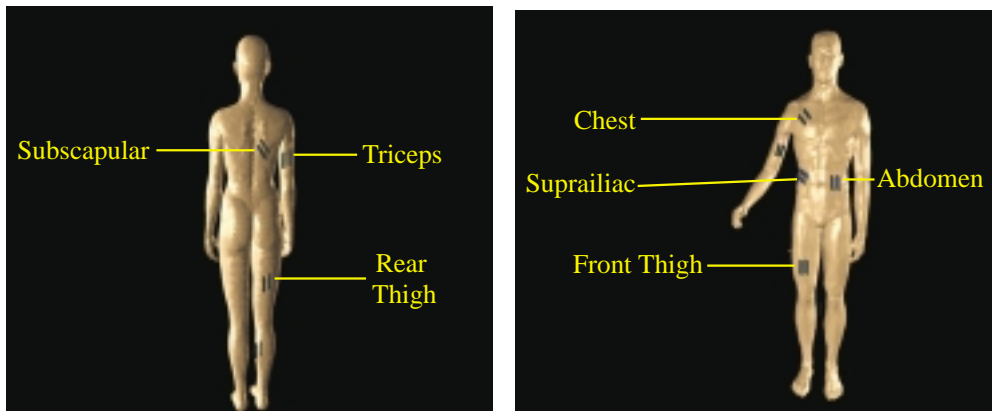


Figure 12.4 Skinfold sites for the measurement of percent body fat using calipers.



Table 12.3 Recording form for skinfold measurements.

Name: _____	
Date: _____	
Age: _____ Weight: _____ Height: _____	
Skinfolds:	Measurement (mm)
Triceps (back of arm)	
Subscapular (back)	
Suprailiac	
Abdomen	
Front thigh	
Rear thigh (women only)	
Chest (men only)	
Sum of 6 skinfolds:	

Skinfolds

- Triceps:** The subject stands with the arm by the side and the elbow extended but relaxed. Measurement is taken on the right arm half way between the acromion and the elbow. The skinfold runs parallel to the long axis of the arm.
- Subscapular:** The subject stands erect with the arm by the side. The measurement is taken just below the inferior angle of the right scapula, running in the direction of the ribs.
- Suprailiac:** The subject stands erect. The measurement is taken 3-5 cm above the right anterior superior iliac spine in the mid-axillary line. The fold runs forward and slightly downward.
- Chest:** (males only) The subject stands erect with arms at the side. The measurement is taken at a point midway between the anterior border of the axilla and the nipple along the lateral border of the pectoralis major muscle, on the right side of the body.
- Abdomen:** The subject stands erect with arms at side. The measurement is taken 3-5 cm to the left of the umbilicus. The fold is lifted parallel to the long axis of the body.
- Front Thigh:** The right foot is placed on a 15 cm step (approximately) with the knee slightly flexed and the muscles relaxed. The measurement is taken on the anterior aspect of the thigh midway between the hip joint and the patella. The fold is lifted parallel to the long axis of the thigh.



Rear Thigh: The right limb is held in the same position as the front thigh measurement. The (females only) measurement is taken midway on the posterior aspect of the thigh between the hip and knee joint. The skinfold is lifted parallel to the long axis of the leg. This measurement is taken on females only.

Sum of Skinfolds (SOS) Method

This method uses six skinfold measurements (Table 12.3). Table 12.4 is used for men while Table 12.5 is used for women. Note that for the males, chest skinfold is used instead of rear thigh skinfold. Table 12.4 and 12.5 are from M.S. Yuhasz, Physical Fitness Appraisal Manual, U of Western Ontario Graphic Services, rev 1988.

For each skinfold measurement, place an (X) at the value nearest your score in the appropriate column in Table 12.4 or Table 12.5. Join the X's to draw a profile chart. This graph depicts body fat deposition or patterning on a relative scale. For example, if you have relatively more fat on your legs than on your arms, you may be classified as "plump" for your thigh skinfold measurement but "average" or "thin" for your triceps skinfold measurement. Fat patterning is genetically influenced. Males and females exhibit typically different patterns of subcutaneous fat distribution. Fat distribution is also peculiar to the individual.

Add the six skinfold measurements, and enter the sum in the "total" column in Table 12.4 or 12.5, depending on the subject's sex. Draw a straight line across from the "total" (sum of six skinfolds) value to the percent body fat value in the next column to the right. This value is the percent body fat of the total body weight. If the subject is a female and the sum of her six skinfold measurements was 110.0 mm, then her percent body fat would be 20%. If her total was 114.5 mm, then her percent fat would be approximately 21.0%, and her percent fat rating would be "average".



Table 12.4 Skinfold measurements (mm) of young men.

Name: _____									
Date: _____									
Weight: _____ (kg)									
Measurements in mm									
Classification	Chest	Triceps	Subscapular	Suprailiac	Abdomen	Front Thigh	Total	% Fat	Score
Deficient									100
		0.0							95
		0.2	0.0			0.0			90
Very Thin		1.2	1.4			1.5	3.1	3.8	85
		2.1	2.8	0.0	0.0	3.1	12.9	4.9	80
	0.8	3.1	4.2	1.2	1.9	5.2	23.7	5.9	75
Thin	2.8	4.0	5.6	3.6	4.3	7.0	32.5	6.7	70
	4.8	5.0	7.0	6.1	6.7	8.9	42.3	7.7	65
	6.8	6.0	8.4	8.5	9.2	10.7	52.3	8.7	60
Average	8.8	7.9	9.8	11.0	11.6	12.6	61.9	9.7	55
	10.8	8.8	11.2	13.5	14.0	14.4	72.0	10.6	50
	12.8	9.8	12.6	15.9	16.4	16.2	81.5	11.5	45
Plump	14.8	10.8	14.0	18.3	18.8	18.1	91.3	12.5	40
	16.8	11.7	15.4	20.8	21.2	19.9	101.1	13.4	35
	18.8	12.7	16.8	23.2	23.7	21.8	110.9	14.4	30
Fat	20.8	13.6	18.2	25.7	26.1	23.6	120.7	15.4	25
	22.8	14.6	19.6	28.2	28.5	25.4	130.5	16.3	20
	24.8	15.6	21.0	30.6	30.9	27.3	140.3	17.2	15
Obese	26.8	16.5	22.4	33.0	33.4	29.1	150.1	18.2	10
	28.8	17.5	23.8	35.5	35.7	30.9	160.1	19.2	5
	30.8	18.4	25.2	38.0	38.2	32.7	170.0	20.1	0



Table 12.5 Skinfold measurements (mm) of young women.

Name: _____									
Date: _____									
Weight: _____ (kg)									
Measurements in mm									
Classification	Triceps	Subscapular	Supra-iliac	Abdomen	Front Thigh	Rear Thigh	Total	% Fat	Score
Very Thin		1.6			5.6	5.1	28.4	< 8	100
	1.1	2.7			8.0	7.4	37.5	< 8	95
	2.9	3.9	0.6	1.1	10.4	9.7	46.5	< 8	90
Thin	4.6	5.0	2.0	3.4	12.8	12.0	55.6	8	85
	6.3	6.1	3.4	5.8	15.2	14.3	64.7	10	80
	8.1	7.2	4.8	8.1	17.6	16.6	73.7	12	75
Desirable	9.8	8.4	6.2	10.4	20.0	18.9	82.8	14	70
	11.6	9.5	7.5	12.7	22.4	21.2	91.8	16	65
	13.3	10.6	8.9	15.0	24.8	23.5	100.9	18	60
Average	15.0	11.8	10.3	17.3	27.2	25.8	109.9	20	55
	16.8	12.9	11.7	19.6	29.6	28.1	119.0	22	50
	18.5	14.1	13.1	21.9	32.0	30.4	128.0	24	45
Plump	20.3	15.2	14.4	24.2	34.4	32.7	137.1	26	40
	22.0	16.3	15.8	26.5	36.8	35.0	146.1	28	35
	23.7	17.4	17.2	28.9	39.2	37.3	155.2	30	30
Fat	25.5	18.6	18.5	31.2	41.6	39.6	164.2	32	25
	27.2	19.7	20.0	33.5	44.0	41.9	173.3	34	20
	29.0	20.8	21.3	35.8	46.4	44.2	182.3	36	15
Obese	31.7	22.0	22.7	38.1	48.8	46.5	191.4	> 36	10
	33.4	23.1	24.1	40.4	51.2	48.8	200.4	> 36	5
	35.2	24.2	25.5	42.7	53.6	51.1	209.5	> 36	0

F. Training Principles

An additional discussion of training and rehabilitation is contained in Unit 11.

To be effective, training must adhere to these general principles:

- **Progressive Overload** - From week to week, the intensity and/or the duration of exercise should be extended.
- **Principle of Diminishing Returns** - Rapid gains in fitness will be noted for the first few weeks, but then the rate of improvement will diminish. The athlete and coach must be patient to avoid overtraining.
- **Recovery** - After strenuous exercise, recovery is essential to allow time for these training gains to take place and to allow further heavy work. Chronic fatigue, lack of training progress and injuries are common outcomes when this principle is over-looked.



- **Specificity** - Exercise effects are specific to the muscle tissues, the oxygen delivery system and the metabolic systems stressed.
- **Maintenance** - Once attained, training gains can be maintained with a reduced overload. This has relevance in the periodized training schedule as some training components need not be continually improved, but stressed just enough to prevent deterioration.
- **Periodization** - Specific fitness components can be stressed at different times throughout the yearly training cycle. Components such as general strength and cardiorespiratory fitness may be stressed during the base training phase while speed and specific skills can be stressed during the competitive season.
- **Individualization** - No two people react the same to the same workout. Individual genetic background, past training experiences, health and other factors influence one's response to a workout. This fact should be acknowledged when planning and executing workouts.

The American College of Sports Medicine has recommended the quantity and quality of exercise to maintain fitness in healthy adults, and this information can be obtained at their web site:

<http://www.msse.org>.

G. Rest, Recovery and Regeneration

An important component of the process leading to a peak performance at a given moment in time is the aspect of “recovery”. In this discussion, “recovery” is the multifaceted element that constitutes a return to homeostatic equilibriums and the potential for an increased level of readiness for some imminent or future performance.

The Complex Interrelationship of Variables

Although recovery is typically used as some “all-encompassing” term, it does in fact refer to many different elements. Figure 12.5 illustrates the main components that influence performance, each of which may be broken down into more specific elements with their own recovery characteristics. The issue of individual differences must be taken into account when discussing any facet of the response to exercise, training, and performance.

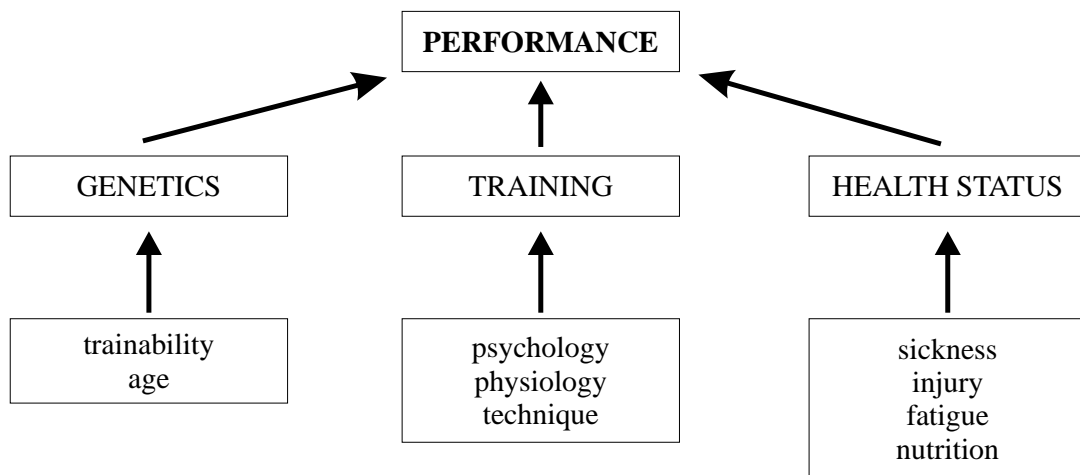


Figure 12.5 Factors in athletic performance.

Figure 12.6 expands these points (from Figure 12.5) and illustrates that performance is not simply isolated to physiological, biomechanical or psychological elements, but involves a complex matrix of all the “stressors” acting upon the individual (or team), including components that would be viewed as “non-training” stressors. The stress placed upon an athlete at any one moment or over a particular period is made up of many factors and is cumulative. All factors have an implication for the recovery of an athlete and their readiness for further training loads or competitive performance.

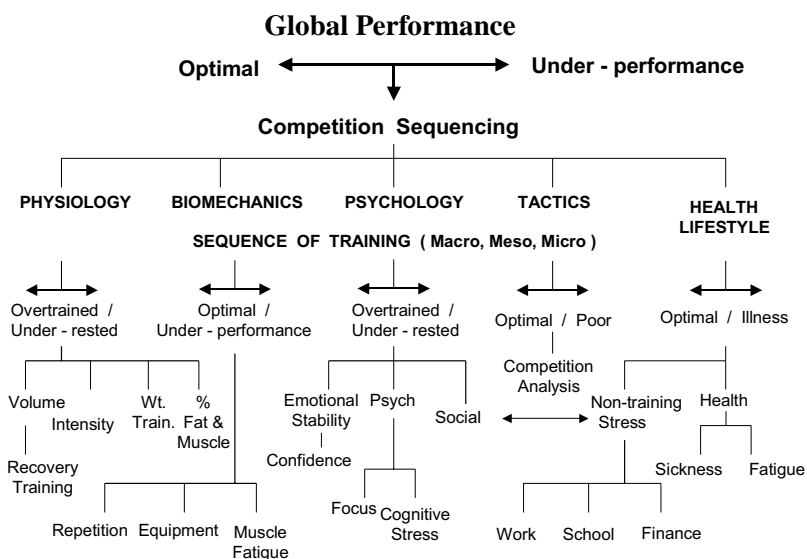


Figure 12.6 Continuum of factors involved in “Global Performance”.

Physical Recovery

The main functions of the recovery period are to:

1. normalize functions from the exercising level back to the pre-exercise state
2. replenish energy resources (and super-compensation)
3. normalize homeostatic equilibriums
4. reconstruct cellular structures and enzymes systems

The first and third components are likely to be achieved within a relatively short period of time (minutes to some hours), whereas the other two components tend to require much longer periods to return to their pre-exercise condition.

In practical terms, there is need to incorporate recovery periods (rest, recovery, and regeneration) into the training process. Such periods are an integral part of the format of training design and if ignored, the final performance outcome is likely to be compromised.

Forms of Physical Recovery

Physical recovery involves either active or passive forms, or a combination of the two.

“Active recovery” typically follows a pattern of low intensity and low volume exercise relative to the current capacity and training load of the athlete. Such recovery is effective immediately following sustained high intensity training or competition, particularly where the anaerobic glycolytic energy pathway has been substantially involved. This low level of activity may also be incorporated into a



longer period of time (perhaps several days) to aid recovery from an extended period of intense training, competition or other non-training stressors (eg. travel).

Well-trained individuals will normally demonstrate rapidly falling heart rates after high intensity exercise, which is synonymous with decreased blood flow to the previously working muscles. It is advantageous to maintain an optimal level of blood flow and, hence, delivery of oxygen and other nutrients, as well as an enhanced removal of potentially disruptive elements (eg. hydrogen and ammonia ions). Low intensity recovery exercise can achieve this by accelerating blood lactate removal as compared to passive recovery.

In practical terms, for well-trained individuals with a sound aerobic base of conditioning, active recovery from a peak post-exercise blood lactate level of approximately 14-18 mmol·L⁻¹ typically has to last 20- 40 minutes to even begin to approach pre-exercise levels. For this active recovery to be successful, the athlete would exercise at a heart rate of around 135-140 b.min⁻¹ if his/her maximal heart rate was 195-200 b.min⁻¹ and resting heart rate was 40-60 b.min⁻¹.

“Passive” (or static) recovery, on the other hand, refers to periods that do not involve any form of activity. These may be of short duration (eg. a few minutes) through to several days (eg. 1-10 days) after the completion of extended periods of arduous training and competition, or as part of the preparation for peak performance. This form of recovery is preferred when there is a priority to restore adenosine triphosphate (ATP) and the high-energy phosphogens after short duration, high intensity efforts (typically less than 15 seconds in duration). It may also be used when there is a priority to restore macronutrients and essential substances, such as water, carbohydrate, protein and fat (see Unit 13 - Nutrition).

Passive recovery measures may also be used to allow for neuromuscular recovery and a restoration of neural movement patterns after intense exercise or loading. Massage and other physical manipulative techniques are often cited as being of benefit in terms of aiding recovery from training and competition, although there is conflicting information from controlled studies as to their real effectiveness.

Specific Aspects of Physical Recovery

Energy stores typically follow a temporal pattern of rapid restoration of the high energy phosphates followed by glycogen. Usually it is observed that ATP levels return to normal prior to phosphocreatine (PCr) levels and glycogen, however, there is some evidence to suggest that this may not always be the case. Such findings would also hint further at the “individualization” aspect of the response to exercise and that, although, the restoration of energy stores are interrelated, there is some “uncoupling” of these pathways dependent upon the specifics of the situation. One aspect that does seem to be strongly evident is the occurrence of a transitory “super compensation” phase for skeletal glycogen and phosphocreatine stores, something that has also been reported for liver and myocardial glycogen content, assuming that an adequate dietary source is available in the hours and days after exercise (see Unit 13 - Nutrition).

Protein synthesis and degradation during post-exercise recovery is also specific to the exercise stress imposed. Therefore, it has been shown that after endurance training the directional trend for the protein adaptive response is towards the mitochondrial proteins of the oxidative-biased muscle fibres, whereas after intensely stressful strength or resistance training, the bias is towards the myofibrillar proteins of the glycolytically oriented fibres. Similarly, disruptive transitory states are documented for the endocrine, immune and central nervous systems, which again emphasize the fact that there are several processes at work in a post-exercise recovery and regeneration phase.



Psychological Recovery

It is well documented that the “psychological profile” and, or, subjective evaluation of intensity (eg. “Rating of Perceived Exertion” RPE) is altered during phases of intense training and high fatigue. Indices such as the “Profile of Mood States” (POMS) have been used to characterize the psychological condition of athletes during various parts of their training and competitive programmes. A common finding from such evaluation is the deterioration of an athlete’s profile from one of relatively positive mental health during “early” season or low training demands to a more disrupted level when undergoing or having completed a phase of intense training. Such disruptions may be alleviated with a reduction in the overall training stress, particularly by removing highly intensive elements and reducing the overall training volume. Regular use of an appropriate questionnaire as a monitoring tool of an athlete’s psychological well-being can assist determining training demands and recovery strategies. (see Unit 14 - Psychology for clinical case histories and further information).

Figure 12.6 indicates that both training and non-training stressors contribute cumulatively to the overall psychological state of the athlete. As with the “physical” stressors, this aspect also emphasizes the need for systematic recovery periods to be built into the training and competition calendar. It may be stated that “stress” summarizes all individual training, non-training, and competition-dependent stress factors and that these may increase the potential for a serious fatigue manifestation or possible “overtraining” situation.

Overtraining

The concept of “overtraining” has received a great deal of attention in recent years, by researchers, the general public and the mass media. Unfortunately, the proliferation of material on the topic has led to an unnecessarily large and muddled associated jargon. One definition of “overtraining” is that it is an imbalance of too much stress and too little recovery. The “overtraining syndrome” has been defined as “an impaired state of health which is caused by overtraining and characterized by particular findings”.

The literature on the characteristics of “overtrained” athletes indicates an extensive array of physical and psychological symptoms that may or may not appear for a particular individual. These characteristics or symptoms include, but are by no means limited to, the following:

- underperformance
- depression
- sleep disturbance
- increased resting heart rate
- increased susceptibility to upper respiratory tract infections and other minor ailments
- irritability and altered mood states
- loss of appetite
- weight loss
- disrupted menstrual cycle
- general feeling of fatigue
- lowered resting heart rate
- cardiac arrhythmia

Although this concept has been continually labeled as “overtraining”, more recent thought has led to a re-evaluation and the introduction of the view that what is actually consistently seen is an “underperformance” by athletes and that this may have different etiologies dependent upon the individual and their specific circumstances (see Unit 3 - Organ System Disorders, section F, for clinical case histories of overtraining and underperformance).



Furthermore, the elements that may or may not be involved are viewed as being on some form of continuum (optimal to sub-optimal; see Figure 12.6) and that there is also an over-riding timing or sequencing from typical short-term training fatigue states, through mild or extensive “overreaching”, to some long-term performance incompetence dependent upon the appropriateness of the recovery and regeneration periods to the training load.

For practical purposes, this sequencing may be expressed as five stages to the fatigue continuum as outlined in Table 12.6. While fully recognizing that these stages actually “flow” into one another somewhat seamlessly, the table provides a framework for expected recovery timelines associated with each of these stages and these are shown in Table 12.6.

Table 12.6. Practical guide to expected recovery timelines.

5 Stages of Fatigue	Time Frame for Recovery
1. Training stress	< 24 hours
2. Overstrain	3-5 days*
3. Training overload	5-7 days
4. Over-reaching	10-14 days
5. Overtraining	> 28 days
*peak soreness ("delayed onset") 24-48 hours	

Practical Guidelines for Managing Recovery, and the “Supplement” Issue

There should be a systematic recovery plan within a training and competition program, based on a practical set guidelines, such as the following:

1. Always strive to maintain a basic level of health.
2. Eat wisely, eat enough and ensure adequate hydration (see Unit 13 - Nutrition).
3. Restoration of energy and water stores before and after training and competition should be a major priority for those engaged in endurance activities (see Unit 13 - Nutrition).
4. Despite the forceful advertising and strong claims made by nutritional supplement companies, there is no evidence to support the vast majority of the purported “ergogenic” substances (see Unit 13 - Nutrition, section I).
5. Supplementation is not an excuse for a poor diet or unwise nutritional practices.
6. Rest, recovery and regeneration periods should be planned as integral parts of the training and competition program.
7. At least one full day per week should be assigned to passive recovery.
8. Allow for full recovery every 2 weeks.
9. Every 4-6 weeks allow for a systematic regeneration period of approximately 1-3 days, in addition to the normal day per week guide.
10. Every 16-22 weeks there should be a more extended period of planned regeneration. This will be in the order of 5-10 days of appropriate measures, some of which will be of a passive nature.
11. Keep a training diary that tracks both training volume (eg. in minutes or hours, metres or kilometers), some attempt to examine intensity (eg. heart rate, RPE, arbitrary scale), and indices of the athlete’s level of well-being and “readiness” or “preparedness” for continued training and competition (eg. resting heart rate, POMS, performance criteria, body mass, fat and fat-free mass).



12. Attempt to “individualize” the training schedule and load (ie. do not blindly follow some famous athlete’s training regime).
13. Establish a sound history of basic training involving a critical mass of low intensity training prior to attempting to increase the percentage of high intensity interval training within a given program.
14. Monitor the easy/light training sessions or days as carefully as you would the hard/intense ones.
15. Most experts suggest limiting the number of really intense training sessions to 2-3 per 7 day cycle.

Ongoing Monitoring

It is essential with world-class athletes to have ongoing monitoring when engaged in longitudinal training and competition programs. This basic rule embraces the concept of “entry and exit” testing or monitoring, whereby particular variables are examined upon entry into, and exit from, a particular phase of training or competition. The variables measured will be largely dictated by the event and training format in question, however, there are likely to be common factors amongst all sports activities (eg. aerobic power, strength). It should also be noted that the competitive event itself is not only the highest form of training, it is also the ultimate test of preparedness.

H. References

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5. Mathews, D & Fox, E. (1976). The Physiological Basis of Physical Education and Athletics, W.B. Saunders Company, Philadelphia.

For further information, refer to the following web sites:

<http://www.geocities.com/HotSprings/8982/exphys.html>

<http://www.krs.hia.no/~stephens/index.html>

<http://ortho84-13.ucsd.edu/home.html>

