Handbook of Sports Medicine and Science

Cross Country Skiing

EDITED BY

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Cross Country Skiing

IOC Medical Commission Sub-Commission on Publications in the Sport Sciences

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Forewords by the IOC

On behalf of the Olympic Movement, I convey my best wishes to the Editor and contributing authors of this valuable publication and to its readership, including fellow medical professionals and coaches working directly with the athletes of the world.

This Handbook covers all relevant areas of the historical sport of cross country skiing which saw its first competitions held at the end of the 19th century and which was included in the programme of the I Olympic Winter Games in Chamonix in 1924. Since that time, this event has developed both in terms of participation and technical difficulty. This publication provides up-to-date informative material as well as serving as an easily comprehensible reference guide.

I wish you all enjoyable reading.

Dr Jacques Rogge
IOC President

Two cross country skiing events were included in the inaugural Olympic Winter Games in 1924, held in Chamonix, France. Thorleif Haug (Norway) won both of the races included in the programme, the Men's 18 km and the Men's 50 km. An event for women was not included in the competition until 1952 when Lydia Wideman (Finland) won the Women's 10 km in Oslo. This sport challenges men and women athletes in the areas of nutrition and physiological conditioning. The longer races represent physical challenges equal to the endurance events of other Olympic sports.

I would like to thank Dr Heikki Rusko and his team of expert authors for having compiled a Handbook that addresses every aspect of the sport: physiology, nutrition, biomechanics, environment, medical considerations, psychology, and equipment. Both basic scientific information and practical applications are presented in a clear and readable style.

For knowledgeable competitors, the Handbook will provide a wealth of valuable information to assist in both conditioning and actual competition.

Prince Alexandre de Merode
Chairman, IOC Medical Commission

Foreword by the FIS

Few other sports have experienced such an explosive growth in interest and participation in past decades as has Nordic Skiing. Originating from Scandinavia and now enjoyed everywhere where nature brings snow to people, a broad spectrum of the population has become fascinated with this sporting activity.

Enthusiastically practised by young and old people of both genders, cross country skiing takes the person out into nature and gives adventure, enjoyment, and regeneration. The aesthetic, comprehensive, and natural motion together with the ease of learning, the small danger of injury, and, especially, the health values, give the quality of 'a higher pace of life' in the context of a sensible use of leisure time.

Internationally recognized experts have taken great pains to summarize the various medical, physiological, biomechanical, and practical aspects of cross country skiing in this Handbook. They have accomplished this in a highly successful manner.

Not only will sports scientists, medical doctors, coaches, and athletes benefit from this publication but also all persons who participate in and enjoy the sport of cross country skiing.

Respect, recognition, and congratulations must go to the Editor and contributing authors of this *Cross Country Skiing* Handbook and special thanks to the International Olympic Committee and its Medical Commission for making this publication possible.

Professor Dr Ernst Raas
Chairman, Medical Committee
International Ski Federation

Preface

Competitive cross country skiing is one of the most demanding sports. It requires a high maximal oxygen uptake, fast force production and ability to resist fatigue, good skiing techniques, and high-quality skis that are well prepared. In addition, a skier has to be able to cope with the stress of Olympic level ski races and to cooperate with coaches, service staff, sponsors, and mass media. Finally, an elite skier has to maintain a state of good health, especially before and during the most important races, in order to stand on the medallists' podium for the international ski races.

The distances of ski races range from 5 to 30 km for women and from 10 to 50 km for men. Recently, sprint skiing races with up to 4 repetitions of distances 1000–1700 m have been included in the programme of international ski competitions. The two different racing techniques, classical and free style, and the new short-distance sprint races have resulted in increased velocities and emphasized the importance of both neuromuscular factors and skiing technique as determinants of high level skiing performance. The training for cross country skiing must be based on a detailed analysis of the determinants of successful skiing performance and, in cross country skiing, the determinants are more abundant than in many other sports. The ski tracks are not constant, environmental conditions can vary considerably, and equipment is employed by both the legs (skis) and the arms (ski poles).

The purpose of this handbook is to bring both basic and applied information on cross country skiing to the coaches, knowledgeable cross country skiers, sports medicine physicians, physical therapists, and other interested readers. The main emphasis is to improve the training and performance of young and adult skiers who want to become elite competitors. In this handbook, probably for the first time, the new models of endurance performance are described and applied to the training for cross country skiing. Similarly, new approaches for successful performance are presented regarding other aspects of the sport.

I wish to acknowledge the Medical Commission of the International Olympic Committee for appreciating the need for this kind of new handbook for the cross country ski community and, in particular, Professor Howard G. Knuttgen for his unfailing support throughout this project. I am grateful to each of the contributing authors for their outstanding efforts, especially to Dr Ola Ronsen, who contributed to the quality of this publication in a major way by sharing the expertise of the Norwegian scientific and medical community as regards cross country skiing.

Heikki Rusko PhD
Jyväskylä, Finland

Chapter 1

Physiology of cross country skiing

Physiological basis of cross country skiing

Regardless of skiing distance, cross country skiing is an endurance sport requiring very high aerobic power and capacity. During prolonged skiing, maximum oxygen uptake ($\dot{V}O_{2max}$) cannot be sustained and, consequently, the ability to ski at high fractional use of the maximum oxygen uptake and the ability to resist fatigue are also important. Fatigue resistance has traditionally been connected to energy supply and depletion of carbohydrate stores.

During short uphill skiing, during the finishing burst and during new sprint skiing the energy demand exceeds maximum oxygen uptake and, consequently, anaerobic energy production has been thought to have an important role in cross country skiing performance.

During a ski-race, several different skiing techniques have to be used. In addition to mastering different skiing techniques, the skiers must select the 'correct' skiing technique for each part of the terrain. The economy of skiing should also be good. The economy and good skiing techniques are related to the function of the neuromuscular system. The ability of the neuromuscular system to recruit the muscles, to produce force and power and to resist fatigue has also been shown to be important for endurance performance.

Cross country ski-races are held at different altitudes, from sea level to 1800 m, and ski-training camps are held at 2500–3000 m altitude. Weather conditions may range from – 20 to + 10°C during ski training and racing.

These factors indicate that even though the traditional $\dot{V}O_{2max}$ is the most important determinant of cross country skiing performance, other determinants of endurance performance are also important. The determinants of $\dot{V}O_{2max}$ have also been questioned and it has been suggested that functional systems not related to oxygen transport and aerobic energy production may even limit $\dot{V}O_{2max}$ and maximum endurance performance. Therefore, the classical theories of endurance performance are re-evaluated and discussed with applications to training for cross country skiing.

The physiological background and significance of the classical and new determinants of cross country skiing performance are discussed in the following sections.

Oxygen transport

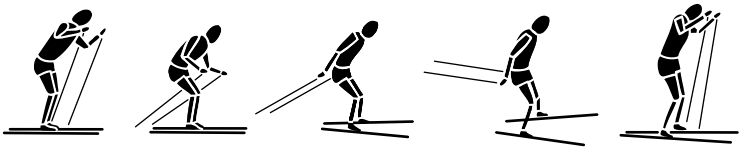
The single most important physiological determinant of cross country skiing performance is maximum oxygen uptake, $\dot{V}O_{2max}$, which integrates the ability of the lungs to transfer oxygen from air to blood, the blood and red blood cells to bind oxygen, the heart to pump blood (maximum cardiac output), the circulation to distribute blood to muscles, and the muscles to use oxygen.

Heart and circulation

$\dot{V}O_{2max}$ is directly proportional to maximal cardiac output, which is believed to be the most important single determinant of $\dot{V}O_{2max}$. The maximum heart rate does not change very much with training; elite skiers have almost the same maximum heart rate as untrained subjects. Consequently, the heart size and stroke volume of the heart are much higher in elite cross country skiers as compared to untrained persons and are responsible for the increase in maximum cardiac output and $\dot{V}O_{2max}$ with training (Table 1.1). The increase in stroke volume is reflected as a decreased heart rate during submaximal exercise (and skiing), and therefore heart rate at constant submaximal exercise intensity can be used as a rough estimate of stroke volume, heart size and $\dot{V}O_{2max}$.

During submaximal exercise, oxygen uptake and cardiac output increase linearly with the increase in exercise intensity (Fig. 1.1). When oxygen uptake is about 50–70% of $\dot{V}O_{2max}$ (heart rate 120–150 b.p.m.), the increase in stroke volume with exercise intensity levels off in untrained persons but in elite athletes stroke volume may increase slightly up to $\dot{V}O_{2max}$. In untrained subjects the increase in stroke volume is

Table 1.1 Comparison of maximal heart rate (HR), stroke volume (SV), cardiac output (CO) and arteriovenous oxygen difference (AvO_2diff) of unfit, fit, junior skier and elite skier having different maximal oxygen uptake ($\dot{V}O_{2max}$). The main differences are seen in the maximal SV and CO.



	Weight (kg)	$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	CO_{max} ($l \cdot min^{-1}$)	HR_{max} (b.p.m.)	SV_{max} (ml)	AvO_2diff ($ml \cdot l^{-1}$)
Unfit adult	75	2.2	30	15	198	75	15
Fit adult	71	3.7	53	23	195	120	16
Junior skier	71	5.2	73	30	190	160	17
Elite adult skier	72	6.3	87	37	185	200	17

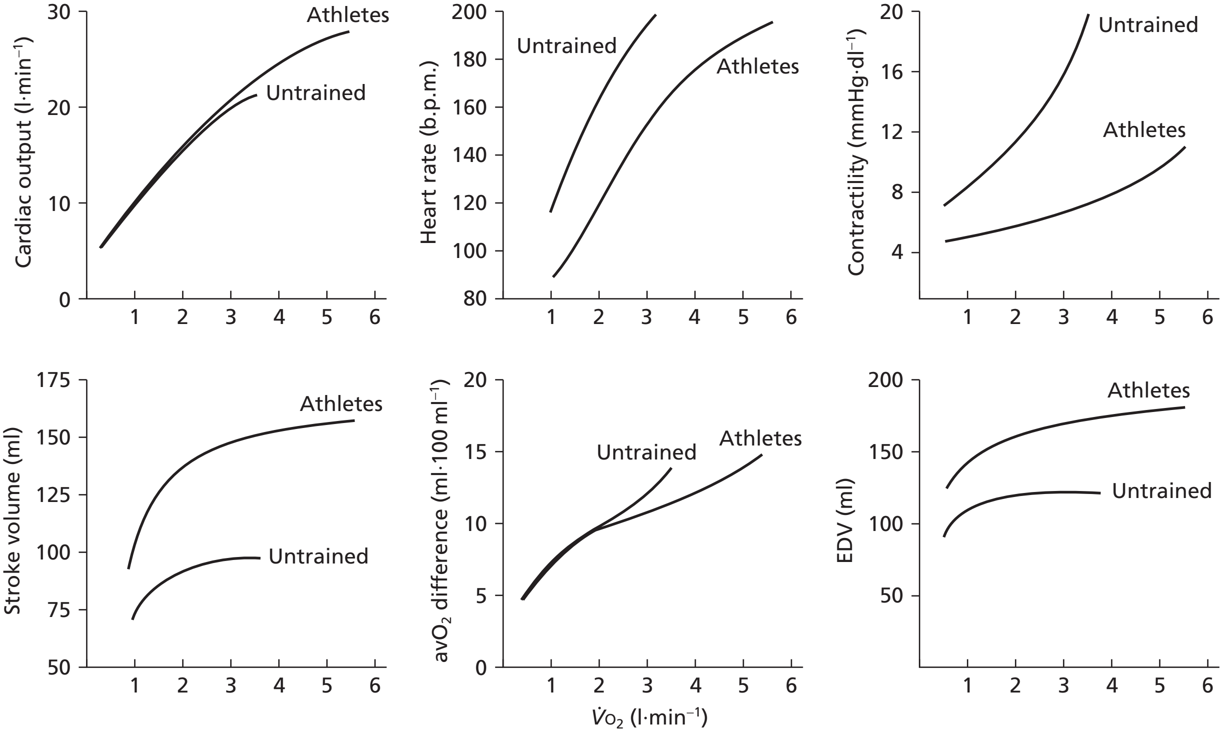


Fig. 1.1 Changes in cardiovascular variables with increasing exercise intensity in untrained persons and elite cross country skiers.

induced by increasing the contractile force of heart muscle, for example by increasing sympathetic activation and stress hormone secretion. Endurance training decreases sympathetic activation and stress hormone secretion, increases blood volume and venous return to the heart and allows the heart to stretch before contraction. Stretching enhances the contraction force of the heart muscle without increasing sympathetic activation and stress hormone secretion so stroke volume is increased (the so-called Frank–Starling mechanism). This allows the heart to do more work and contract more economically so the potential for high maximal cardiac output is increased. During prolonged exercise (>1–2 h) stress hormones may be depleted and heart muscle is forced to stretch before contraction.

In young athletes the left ventricular end-diastolic diameter seems to increase with training while in adult endurance athletes, including skiers, a further increase in $\dot{V}\text{O}_{2\max}$ and cardiac output is explained by the increase in both left ventricular end-diastolic diameter and wall thickness and by the decrease in end-systolic diameter. Many cross country skiers have enlarged hearts, so-called 'athlete's heart', with increased end-diastolic left ventricular diameter and wall thickness.

Blood

Total mass of red blood cells (RCM), haemoglobin mass (HbM) and total blood volume (BV) are the most important blood variables for elite cross country skiers. Haemoglobin (Hb) concentration and haematocrit (Hct) usually adjust to the optimal individual level for each skier. If RCM, HbM and Hb are increased by endurance training, $\dot{V}\text{O}_{2\max}$ also increases. The Hb concentration of elite cross country skiers does not differ considerably from that of untrained people because plasma volume usually increases concomitantly with the increase in HbM and RCM. Consequently, the increased blood volume allows increasing venous return from muscles to the heart during exercise. This in turn increases stroke volume by stretching heart muscle and thereby maximal cardiac output also increases.

During the last 20–30 years, cross country skiers have steadily increased their altitude ski-training camps on snow during summer training periods and the number of World Cup races at altitude has also increased. This has increased their RCM and blood volume. Haemoglobin concentration has also slightly drifted upwards but is still within the normal population values (Table 1.2; see also Chapter 5).

An increase in oxygen transport capacity by blood transfusions or erythropoietin treatment significantly increases $\dot{V}\text{O}_{2\max}$ and endurance performance. However, increasing BV by infusing plasma expanders may not increase the $\dot{V}\text{O}_{2\max}$ of elite endurance athletes.

Table 1.2 Total volume of red cell mass, plasma volume, blood volume, haematocrit and haemoglobin concentration of elite cross country skiers and untrained persons.

	Untrained	Elite skier
Red cell mass (l)	2.2	3
Plasma volume (l)	2.8	3.6
Blood volume (l)	5	6.6
Haematocrit (%)	44	45
Haemoglobin (g·l^{-1})	155	160

Respiration

The main function of respiration is the exchange of oxygen and carbon dioxide between ambient air and blood. Previously, lung ventilation and transport of oxygen from alveoli to blood was not considered to be an important determinant of $\dot{V}\text{O}_{2\max}$ at sea level, while at altitude respiration was thought to limit $\dot{V}\text{O}_{2\max}$. Several recent studies have shown that the arterial blood of elite endurance athletes, including cross country skiers, is not fully saturated with oxygen during submaximal and maximal exercise at sea level and this desaturation is more enhanced during exercise at low (<1000 m) and moderate altitude (1500–3000 m) (Fig. 1.2).

During maximal skiing at the intensity of $\dot{V}\text{O}_{2\max}$, the lung ventilation of elite skiers may increase up to and over 200 l·min^{-1} (BTPS) and cardiac output up to 40 l·min^{-1}. The extraction of oxygen from alveolar air is then decreased, probably because of the short transit time of blood (caused by high cardiac output) in the alveolar capillaries.

During maximal exercise the oxygen consumption of respiratory muscles may be 5–10% of the $\dot{V}\text{O}_{2\max}$ and respiratory muscles may also produce lactate even during submaximal exercise. If the lung ventilation during ski-racing is close to individual maximal voluntary ventilation, the respiratory muscles may fatigue. The inability to attain as high $\dot{V}\text{O}_{2\max}$ and maximal ventilation after the race compared to before, may be caused by fatigue of the respiratory muscles. During cross country skiing the ability to keep up high ventilation and to resist respiratory muscle fatigue may therefore be a very important determinant of race performance.

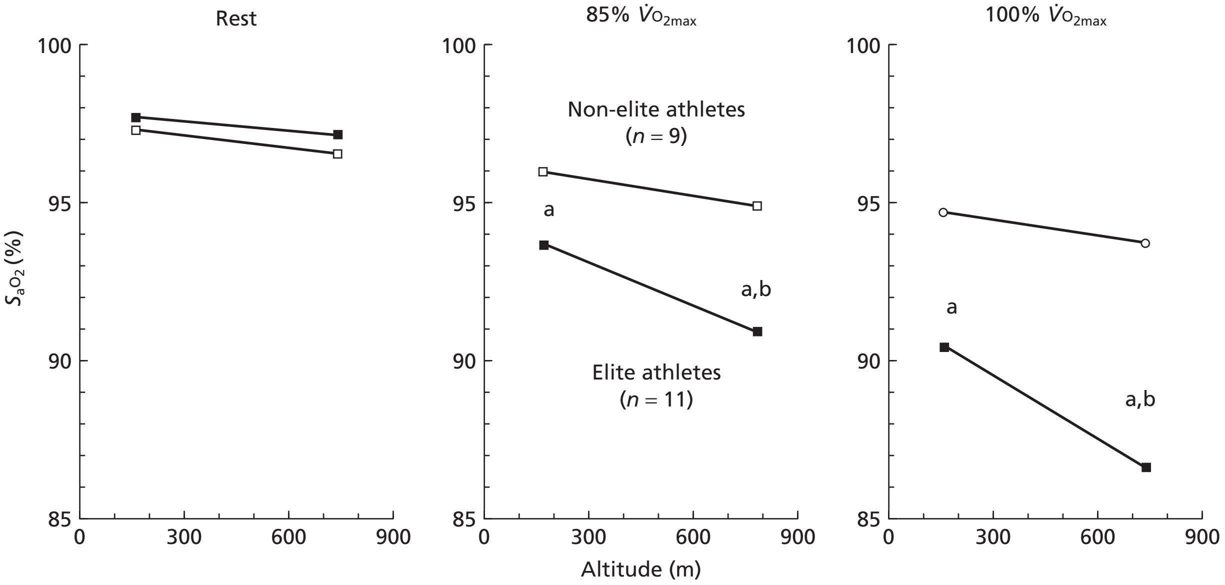


Fig. 1.2 Oxygen saturation of blood (S_aO_2) at rest and during submaximal and maximal exercise at sea level and at low altitude in elite ($\dot{V}O_{2max}$ 5.5 l·min^{-1}) and non-elite ($\dot{V}O_{2max}$ 4.0 l·min^{-1}) athletes. Oxygen saturation of blood of elite athletes is decreased during submaximal and maximal exercise even at sea level and a further decrease is observed at altitude less than 1000 m. (a) Significant difference between elite and non-elite athletes. (b) Significant difference between sea level and low altitude. (Modified from Gore *et al*. 1996.)

Peripheral oxygen utilization

As shown by the arterial–venous oxygen differences in Table 1.1, peripheral factors do not seem to be very important for $\dot{V}O_{2max}$. During prolonged exercise, such as 30 and 50 km ski-races, capillarity, number of mitochondria and oxidative capacity of muscles may be more important. It is well known that the activity of oxidative enzymes in both leg and arm muscles of cross country skiers is high. However, in leg muscles they are the same or slightly lower than in distance runners or cyclists, although the $\dot{V}O_{2max}$ of cross country skiers is the highest. The mitochondrial enzyme activities adjust quickly to changes in training load and during the competitive season and taper training the oxidative capacity in the muscles of cross country skiers decreases with considerably decreased training volume but their $\dot{V}O_{2max}$ stays high.

The higher $\dot{V}O_{2max}$ of cross country skiers during skiing as compared to treadmill running suggests that some peripheral factors are important. These factors are related to the increased muscle mass and the increased oxidative enzyme activity in those muscles that are recruited during skiing. An increased blood flow to the specific skiing muscles may also explain the difference (see also section on Maximum oxygen uptake of cross country skiers).

Clearance of lactate produced during uphill skiing is dependent on the characteristics of muscle tissue, not only in the exercising muscles but also in less active muscles (see section on Fractional utilization of $\dot{V}O_{2max}$). The peripheral characteristics of utilizing oxygen and producing energy are related to the muscle fibre type (see section on Energy for skiing).

Main points to remember about oxygen transports

- The most important determinant of maximum oxygen uptake is the function of the heart and maximum cardiac output.
- Elite cross country skiers have high blood volume, total volume of red blood cell mass and total volume of haemoglobin mass.
- The haemoglobin concentration of cross country skiers is usually within normal limits because plasma volume is also increased; however, with several years of endurance

training and altitude training, Hb concentration may increase slightly in elite skiers.
- Oxygen saturation of blood of elite cross country skiers is decreased during maximal and submaximal exercise at sea level and further decreased at low to medium altitude.
- The ability to keep up high lung ventilation may be an important determinant of ski-race performance.
- Peripheral factors of oxygen utilization do not limit maximum oxygen uptake but they may be important during 30–50 km ski-races.

Energy for skiing

Cross country skiing requires huge amounts of energy to be produced from food (carbohydrates, fats and proteins). These fuels yield adenosine triphosphate (ATP) which provides the immediate energy source for muscle contractions and cell functions. ATP stores in the muscles are very small and the cells have to produce new ATP all the time. The main sources for ATP resynthesis are:

1 another high-energy phosphate compound, phosphocreatine (PCr), in the muscle;

2 the glycolytic breakdown of muscle carbohydrate stores (glycogen); and

3 the oxidative breakdown of carbohydrates, fats and proteins.

Energy demand and yield during ski-races

The energy demand of ski-races and energy yield from aerobic and anaerobic energy production as well as the utilization of carbohydrates (CHO) and fats are presented in Table 1.3. The total energy demand of 50 km skiing is almost independent of the time taken; skiing 50 km at low training pace requires as much energy as 50 km at race pace if the skiing conditions (weather, track, skis, waxing, etc.) are the same. From the point of view of energy production, the limiting factor for energy yield is oxygen transport and therefore the energy equivalent ($kJ \cdot l^{-1}$ O_2) of substrates also has an influence. For carbohydrates, fats and proteins the energy equivalent is 21, 19.5 and 19 $kJ \cdot l^{-1}$ O_2, respectively.

The figures for aerobic and anaerobic contribution in Table 1.3 are average values and change during the race. For instance, during sprint ski-racing the share of anaerobic energy production is ~100% in the beginning, 60–70% after the first 20 s, decreasing to 40–50% during the last half of the race and increasing to about 50–60% during the finishing spurt. Similarly, during the longer ski-races the share of anaerobic contribution varies as a result of the terrain (uphill and downhill sections). During short steep uphill skiing in a 30-km ski-race the oxygen demand has been calculated to increase up to 100–120 ml·kg·min exceeding $\dot{V}O_{2max}$ and the anaerobic share can temporarily increase up to 20%. The average share of aerobic and anaerobic energy yield depends on the distance of the ski-race but, generally speaking, the role of anaerobic energy production is low (Table 1.3).

Anaerobic energy production and blood lactate concentration

ATP concentration in the muscles is well regulated and does not decrease much even at maximal

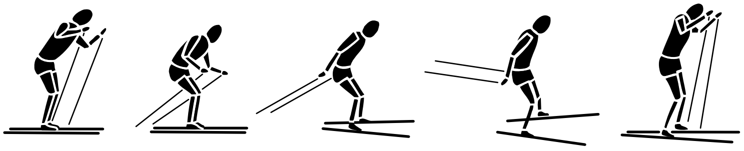


Table 1.3 Energy demand and contribution to energy output from aerobic and anaerobic processes and utilization of fats and carbohydrates (CHO) during ski races.

Distance/time	Energy demand (kJ)	Aerobic/anaerobic (%)	Fats/CHO (%)
1 km/2 min (sprint)	400	50/50	1/99
5 km/15 min	1600	90/10	5/95
10 km	3000	95/5	10/90
15 km	4500	97/3	20/80
30 km	9000	99/1	40/60
50 km	15 000	99/1	50/50

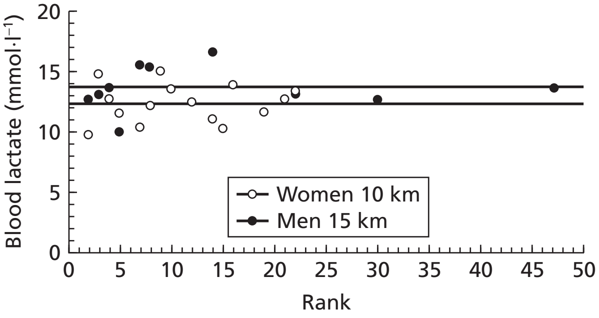


Fig. 1.3 Blood lactate concentration after women's 10 km and men's 15 km classical race in the Finnish championships in 2000 indicating no relation with the final position or rank in the race (mean ± SD 12.4 ± 1.6 and 13.9 ± 1.8 mmol for women and men, respectively). (Rusko, unpublished data.)

anaerobic exercise. Instead, muscle PCr stores are partly depleted in the beginning of submaximal or maximal exercise but, thereafter, the PCr concentration in the muscle stays at a lowered level depending on the exercise intensity. This suggests that PCr is also resynthesized rapidly during exercise (Fig. 1.3).

Based on studies during different laboratory exercises, it can be estimated that PCr stores are depleted by 30–70% during the first 1–2 min of skiing and thereafter the PCr content of leg muscles oscillates from almost 0 to 50–60% according to the uphill and downhill sections, respectively. During recovery, the half-time of PCr resynthesis is about 20–30 s which means that about 75% of PCr stores could be resynthesized during 1–2 min recovery. During downhill sections leg muscles are not fully relaxed and blood flow to leg muscles may be limited because of static muscle exertion. Therefore, the replenishment of leg muscle PCr stores is limited during downhill sections, at least if gliding posture is low. However, upper body muscles may be able to replenish most of their PCr stores during long downhill sections.

Anaerobic energy yield via glycolysis is also activated together with the utilization of PCr stores and glycolytic energy yield is greatly enhanced if the energy demand of skiing exceeds $\dot{V}O_{2max}$. Glycolysis is the breakdown of muscle glycogen resulting in the production of ATP, pyruvate and H^+. If there is not enough oxygen, further 'oxidation' is limited and lactic acid is produced. Some of pyruvate can also be synthesized to alanine and transported together with lactate from muscle to blood.

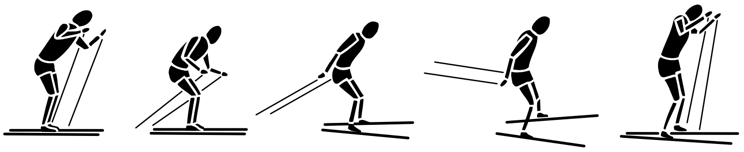
Lactate is produced in the muscles even during low-intensity aerobic exercise without continuous accumulation of blood lactate. Lactate is probably used in the adjacent muscle fibres and is also transported to blood. Lactate is removed from blood to some other less active muscles and the heart where it is used for oxidative energy production, and to liver where it is transformed back to glucose. Similarly, alanine is transported to the liver. During ski-racing most of the lactate is oxidized in adjacent muscle fibres, other less active muscles and in the heart.

During high-intensity exercise, anaerobic energy is produced at high rates, more pyruvate is converted to lactic acid and acidity increases. This increased acidity is known to inhibit ATP production and to impair the contractile force of muscle. The ability to resist the increase of acidity might therefore limit high-intensity exercise of short duration, e.g. sprint skiing. When lactate is produced in the muscles and blood lactate concentration increases during ski-racing, the acidity is buffered by both intramuscular and blood buffers. If the individual buffer capacity is exceeded the acidity starts to increase very rapidly.

During ski-racing blood lactate concentration increases quickly during the first 5–10 min of skiing to 5–10 $mmol{\cdot}l^{-1}$ and thereafter slowly increases up to the finish of the race. However, the lactate turnover in the body is high during the race. Lactate is produced during short steep uphill skiing so that the oxygen deficit between the oxygen demand of uphill skiing (e.g. 100–120 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) and $\dot{V}O_{2max}$ (85–95 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) is replaced by anaerobic energy yield and lactate production. Thereafter, during the downhill sections of the race, oxidative processes in muscles and the heart are used to remove lactate from the blood and keep the concentration in blood within tolerable limits. Studies on junior national ski-team members have shown that slight changes in the starting velocity considerably influence the blood lactate accumulation during the first 1–2 km of the race (Table 1.4).

The blood lactate concentration measured after a ski-race depends on the distance of the race and on the individual buffer capacity–anaerobic capacity. Great individual differences have been measured. The blood lactate concentration of skiers after the Finnish and Swedish championship ski-races in the 1970s and 1980s after the women's 5 km race ranged from 6 to 20 $mmol{\cdot}l^{-1}$ and after the men's 15 km race from 7 to

Table 1.4 Effect of slightly different starting velocities on blood lactate accumulation in the Finnish national junior team. (Modified from Kantola & Rusko, 1985.)



Female skiers ($n = 6$)	Male skiers ($n = 6$)				
Time at 1.4 km (s)	Velocity (m·s^{-1})	Lactate (mmol·l^{-1})	Time at 1.7 km (s)	Velocity (m·s^{-1})	Lactate (mmol·l^{-1})
270	5.19	7.0	364	4.67	7.9
263	5.32	8.6	355	4.79	9.6
256	5.47	10.6	350	4.86	10.7
After 5 km race		12.8	After 15 km race		12.0

19 mmol·l^{-1}. In the winter season of 1999–2000 the blood lactate concentration of national team skiers in the Finnish championship ski-races after the women's 10 km race ranged from 9 to 15 mmol·l^{-1} and after the men's 15 km race from 10 to 17 mmol·l^{-1}. After 30–50 km races the highest values have ranged between 3 and 10 mmol·l^{-1}. The low blood lactate concentration after longer distances most probably depends on the depletion of muscle glycogen.

Results from the Finnish championships have shown that fast starters (who probably started faster than their maximum aerobic power allowed) had significantly higher blood lactate concentration at the finish line than those skiers who started slower, at presumably optimal velocity (Fig. 1.4). The increase in blood lactate concentration and acidity influenced the decrease in the skiing velocity of the fast starter so that despite the average 6 s lead at 2.7 km, the final time was 3 s slower compared to a skier who started at optimal velocity. The skiing velocity started to decrease first in uphill sections and, when acidity increased further, also in flat and downhill sections.

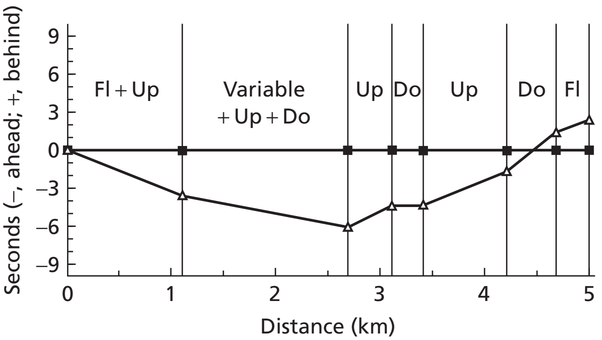


Fig. 1.4 Skiing velocity in two female national team skiers with 'high' (△, 17.4 mmol·l^{-1}) or 'low' (■, 11.1 mmol·l^{-1}) blood lactate after the race. The 'high' skier had a lead of 6 s after 2.7 km but thereafter her skiing velocity started to decrease and she finished with a 2-s defeat. The velocity started to decrease first in the uphill (Up) and then in downhill (Do) and flat (Fl) sections. (Modified from Kantola & Rusko 1985.)

Aerobic energy production and substrate utilization

Aerobic breakdown of carbohydrates and fats is the primary energy source for ATP resynthesis during cross country skiing, demanding extremely high ability to utilize oxygen in the exercising muscles. Carbohydrates and fats are first broken down in the sarcoplasm of muscle fibres to smaller molecules, which are transported into mitochondria where the reactions catalysed by the mitochondrial enzymes produce large amounts of ATP. Carbon dioxide (CO_2) produced during breakdown of fuels is a byproduct of oxidative metabolism and venous blood transports CO_2 to the lungs. The main enzymes describing the potential for aerobic energy production from carbohydrates are citrate synthase (CS), succinate dehydrogenase (SDH) and cytochrome oxidases. The main factor influencing fat oxidation is the availability of fat in blood and one of the key enzymes is lipoprotein lipase, in addition to mitochondrial enzymes. If large amounts of carbohydrates are broken down and used for ATP resynthesis, the fatty acid oxidation for energy production is inhibited.

Substrate utilization depends very much on the duration of the race (Table 1.3) and on the diet before the race. During a 5-km race the share of energy yield from fat is small. During a 50-km race the share of carbohydrates is on average 50–60%, but it changes considerably during the race. After glycogen loading the share of carbohydrates may be 70–80% during the first 10 km but may be < 20–30% during the last 5–10 km. The share of muscle glycogen breakdown may decrease to 5–10%. During the race the contribution of blood glucose (from liver glucose production and digested carbohydrates) may increase from 5–10 to 20–40% of total energy yield while fat utilization may increase up to 60–70%.

Blood glucose levels depend on the breakdown of liver glycogen, the synthesis of glucose in liver from amino acids and lipids (and from lactate), and on ingested and digested carbohydrates. Stress hormones (adrenaline and cortisol) are important for initiating glycogen breakdown in both muscles and liver, and glucose production in liver. In liver glucagon also enhances glycogen breakdown and glucose production. Insulin enhances transport of glucose from blood into muscle fibres.

Heart muscle, at rest and during exercise, utilizes both lipids and carbohydrates but, with the increase in exercise intensity, the share of carbohydrates can increase up to 60–90% and then heart muscle may also use blood lactate as a substrate for energy yield.

Nervous tissue and red blood cells do not have their own energy stores and their energy production is dependent on oxygen and glucose in blood. If blood oxygen and glucose levels fall, the central nervous system starts to show signs of fatigue. It has also been suggested that central nervous system fatigue is caused by a reduction of the concentration of branched-chain amino acids in the blood and a concomitant increase in tryptophan uptake into the brain. In the brain, tryptophan is then converted into serotonin, which is associated with feelings of fatigue.

Lipids used by muscles come from adipose tissue (free fatty acids, FFA), intestines and liver, and from the muscles' own fat stores. The most important factors for fat utilization are FFA concentration in blood and blood flow to muscles. Lipid mobilization is a relatively slow process activated by the hormones adrenaline, noradrenaline and growth hormone. Insulin seems to inhibit lipid mobilization and to increase the storage of fat.

Proteins are composed of amino acids and most of the proteins are digested into amino acids in the intestines. The breakdown of amino acids can be responsible for 5–10% of total energy production during prolonged exercise. Protein breakdown and amino acid utilization may increase if stress hormone concentrations in blood are continuously high, e.g. during overtraining. Enhanced utilization of amino acids increases the production of nitrogen-containing compounds such as urea. During prolonged exercise, alanine is formed from pyruvate in the muscle and glucose is formed from alanine in the liver, helping to keep up the blood sugar level (Fig. 1.5).

Muscle glycogen

Fatigue during a prolonged training session or ski-race is associated with the depletion of muscle glycogen stores in arm and leg muscles. Supercompensation of muscle (and liver) glycogen stores by pre-exercise carbohydrate loading and carbohydrate ingestion during exercise can delay the onset of fatigue and improve endurance performance. Glycogen depletion is not only related to the exhaustion time, but low concentration of glycogen may also decrease the race velocity before exhaustion. The ability to produce anaerobic energy, as shown by low blood lactate concentration, is also decreased when muscle glycogen stores are almost depleted (Table 1.5).

Improved fatigue resistance during prolonged exercise is not dependent on the higher utilization of carbohydrates but on the high initial glycogen stores and also on the ability to spare carbohydrate stores as long and as much as possible. Higher rate of carbohydrate utilization during prolonged exercise does not improve race velocity. In addition to the direct connection between carbohydrate depletion and exhaustion, there may also exist mechanisms so that low glycogen and blood glucose are recorded by some receptors which give feedback to the central nervous system (CNS) and thereby influence muscle recruitment and the development of CNS-related fatigue.

During cross country skiing muscle glycogen is extensively used during uphill skiing for anaerobic

Fig. 1.5 Exhausted Jana Saldova after the Nagano Olympic 15 km ski race. Fatigue may be related to both glycogen depletion and neuromuscular fatigue. Photo © Allsport/J. Jacobsohn.

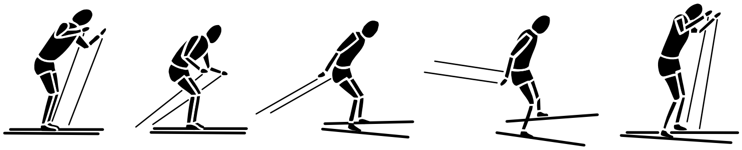


Table 1.5 Muscle glycogen depletion and blood lactate accumulation during Lahti World Cup ski-race in 5 women and 3–5 men Finnish national team skiers. The highest individual lactate concentration is given in parentheses. (From H. Rusko, unpublished data.)

	Women 10 km	Men 15 km	Men 50 km
Muscle glycogen (mmol·kg^{-1})			
Before	110	106	160
After	59	62	17
Blood lactate (mmol·l^{-1})			
Before	0.8	1.1	0.8
After	8.2 (15.4)	9.5 (12.1)	3.3 (4.4)

energy yield. During double poling, when small muscle mass is working, muscle glycogen is used faster from the recruited arm muscles than during diagonal stride skiing. Measurements taken during the Lahti World Cup ski-race have shown that during 10–15 km ski-races glycogen stores decreased to 50% and during a 50-km race to 10–15% of the starting level (Table 1.5). Swedish studies have shown that glycogen is similarly depleted from leg and arm muscles, but during long ski-races the arm muscles may be totally depleted and fatigued. Because of the more static muscle contractions (legs) and greater use of double poling (arms), muscle glycogen depletion is probably faster during freestyle (skating) than during classical (diagonal) skiing. During training and racing at altitude muscle glycogen is also used faster than at sea level.

Carbohydrate loading increases the initial glycogen stores but it also increases the utilization of glycogen. Fat loading decreases both glycogen stores and glycogen utilization. After carbohydrate loading, a mixed diet during the last 12–24 h decreased blood lactate accumulation in the beginning of a trial ski-race, suggesting that glycogen utilization was decreased.

Endurance training also increases the ability to use fat as a fuel and the ability of the liver to synthesize and release glucose from fats and amino acids. Glycogen stores in liver increase at a similar rate to muscle glycogen during carbohydrate loading and are depleted in 1.5–3 h during prolonged exhaustive exercise.

The replenishment of glycogen stores should be started as soon as possible after demanding training or racing (see Chapter 5; Nutritional advice for cross country skiers, and Carbohydrate loading and fluid replacement).

Blood glucose

At rest the blood glucose level is about 1 $g \cdot l^{-1}$ blood and glucose production to and uptake from blood <0.5 $g \cdot min^{-1}$. During exercise, glucose production and release to blood increases in relation to exercise intensity and at the intensity of 70–90% of $\dot{V}O_{2max}$ it may increase up to 2 $g \cdot min^{-1}$. Glucose uptake to muscles is dependent on the depletion of glycogen from muscle fibres. Because of similar glucose production to and uptake from blood, blood sugar levels do not change considerably during prolonged exercise.

In elite endurance athletes, half of the glucose released into the blood is brought about by liver glucose production from liver glycogen, amino acids and fat, and the remainder from digested carbohydrates. Ingesting carbohydrate-containing drinks during exercise can increase the amount of digested glucose and keep up the blood glucose level (see also Chapter 5; Nutritional advice for cross country skiers, and Carbohydrate loading and fluid replacement). However, large amounts of carbohydrate drinks before races also increases insulin concentration, which may lead to decreased blood glucose concentration before and at the beginning of the race, and to increased muscle glycogen utilization.

Use of fats

The importance of fat utilization is obvious during prolonged exercise when muscle glycogen stores are depleted. During exhausting exercise an elite athlete and an untrained person may use almost as much glycogen but the main difference between them is that the elite endurance athlete is able to use much higher amounts of fat before exhaustion. In addition, during interval-type exercise with numerous repetitions, such as cross country skiing, fat utilization is enhanced. During short maximal exercise fat mobilization and utilization is inhibited by lactate production and acidity; even a low lactate concentration (3–4 $mmol \cdot l^{-1}$) has diminished FFA concentration in blood. However, elite cross country skiers are able to utilize large amounts of fat even though the relative exercise intensity is 90% of $\dot{V}O_{2max}$ and blood lactate concentration is ~8 $mmol \cdot l^{-1}$.

FFA concentration in blood and utilization in muscles increases considerably 10–20 min after starting exercise. Thereafter, fat utilization is related to the depletion of muscle glycogen stores and to the decrease in blood glucose level.

High fat content food and diet increase FFA concentration in blood and utilization of fats and, concomitantly, glycogen depletion is slower, lactate production decreases and elite endurance athletes' exhaustion time may be longer. Drinking coffee before the race can also increase blood FFA concentration and be beneficial, especially at altitude. During prolonged exercise and during fasting the liver starts to produce more and more ketone bodies which muscles can use for energy production. Brain tissue may also 'learn' to use ketone bodies if blood glucose levels are low.

Superior endurance performance is related to the increased capacity to oxidize fat and to the sparing of carbohydrates by using them at as low a rate as possible to be able to maintain the desired race pace.

Main points to remember about energy for skiing

- Aerobic energy production is the most important source for ATP replenishment in cross country skiing.
- Anaerobic power does not limit skiing performance; instead, anaerobic capacity is important for sprint skiing and during uphill skiing in long ski-races.
- High acidity related to lactate production may negatively influence skiing performance by inhibiting ATP production and impairing the contractile force of muscles.
- Carbohydrate loading, muscle glycogen sparing, blood glucose maintenance and fat utilization are important during 20–50 km ski-races.

Neuromuscular factors

The demands for good skiing technique, economical skiing and fast sprint skiing emphasize the importance of the neuromuscular system in cross country skiing. The functional ability of the neuromuscular system should be maintained during ski-races of different durations when both oxygen uptake and blood lactate concentration is high.

Neuromuscular structure and function and muscle fibre composition

Motor centres of the CNS activate muscles via motor pathways. From the point of view of motor functions, the main sections of the CNS are the motor cortex, basal ganglia, cerebellum, brainstem and spinal cord. The CNS sends out signals to the skeletal muscles to create the desired motor responses. The last functional unit is referred to as a motor unit, which consists of a single motoneurone innervating a few to several hundred muscle fibres. Muscle fibres in each motor unit contract simultaneously according to the activation of the motoneurone. All fibres in a motor unit are either fast or slow and their contractile and metabolic characteristics are similar. The slow twitch (ST) fibres have relatively slow contractile speed, high proportion of slow-type myosin molecules, high oxidative capacity, low glycolytic capacity and high fatigue resistance. The fast twitch (FT) fibres have fast contractile speed, high proportion of fast-type myosin molecules and high glycolytic capacity. In cross country skiers, almost all FT fibres have increased oxidative capacity and moderate to high fatigue resistance and are called fast oxidative fibres.

Most skeletal muscles contain both ST and FT motor units. Muscle fibre composition (percentage of ST fibres in muscle, %ST fibres) has been believed to be determined genetically or early in life. With age and training, muscles tend to loose FT fibres and, consequently, %ST fibres increases. Cross country skiers have predominantly ST fibres in their leg and arm muscles (Fig. 1.6). The variability is high, but elite skiers with high maximum oxygen uptake seem to have slightly higher %ST fibres than less successful skiers. Skiing extensively for 1–2 months increases the intermediate fibres. Studies of cross country skiers have shown that after 8 years' training the %ST fibres of elite skiers increased significantly from 57 to 68% when they had doubled their training volume and their $\dot{V}O_{2max}$ had also significantly increased. During those same years %ST fibres decreased significantly in

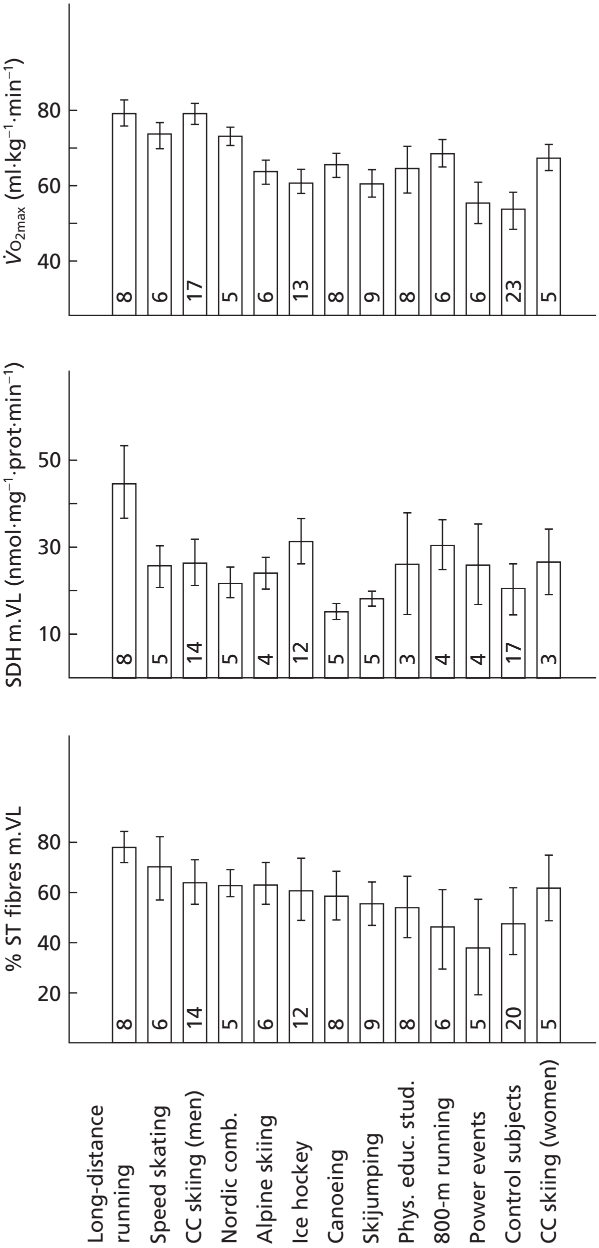


Fig. 1.6 $\dot{V}O_{2max}$, percentage of slow twitch (%ST) fibres and succinate dehydrogenase (SDH) activity of athletes from different disciplines. Both female and male elite cross country skiers had on average 60–65% ST fibres in their vastus lateralis muscles. SDH activity of male skiers was lower than that of elite male distance runners but $\dot{V}O_{2max}$ was the same in both groups. (From Rusko *et al.* 1978.)

the control skiers who had stopped their training and whose $\dot{V}O_{2max}$ had decreased significantly.

Studies on untrained persons suggest that those with high %ST fibres attain the greatest increase in $\dot{V}O_{2max}$ during training. In both male and female skiers those with higher %ST fibres have also been able to increase their $\dot{V}O_{2max}$ more than those with lower %ST fibres. However, ‘FT-skiers’ have been able to increase their $\dot{V}O_{2max}$ as much as ‘ST-skiers’ when their training volume and the volume of intensive training has been high; the ‘FT-skiers’ have to train more and probably better than some talented ‘ST-skiers’.

Despite the correlations between muscle fibre type and $\dot{V}O_{2max}$, the muscle fibre type composition and high oxidative capacity of muscles seem to be more related to the use of substrates and fatigue resistance than to the attainment of $\dot{V}O_{2max}$. Skiers with high %ST fibres have also been able to increase their ‘anaerobic threshold’ more than skiers with low %ST fibres.

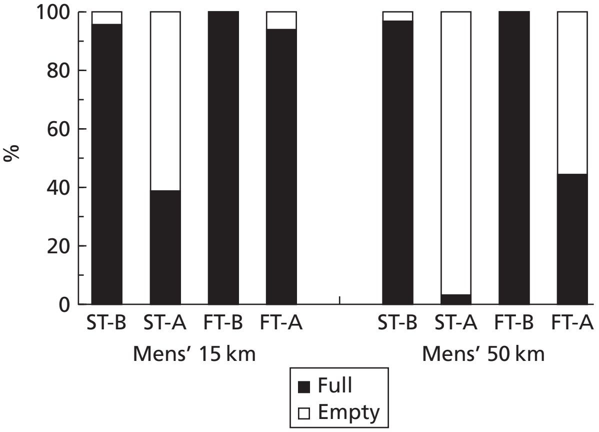


Fig. 1.7 Depletion of muscle glycogen from slow twitch (ST) and fast twitch (FT) fibres of national team skiers during the international ski-race in Lahti (see Table 1.5). Black colour denotes fibres with full or almost full glycogen stores and white colour denotes empty or almost empty fibres. B, before race; A, after race. (Modified from Kantola & Rusko 1985.)

Force production and coordination of muscle fibre activation

More force is produced by activating more motor units at a time and/or by increasing the firing rate of the motor units. With increasing exercise intensity, integrated electromyographic (IEMG) activation increases and the increase is accelerated when approaching $\dot{V}O_{2max}$. During prolonged exercise muscle fibres become fatigued and more IEMG activation is needed to keep up the same velocity. The recruitment of motor units has been studied by analysing the glycogen depletion from different muscle fibres. The recruitment seems to be selective, depending on the requirements of the activity being performed. During low-intensity aerobic exercise mainly ST fibres and motor units are recruited. During more intensive exercise FT fibres and motor units are also recruited.

In cross country skiing muscle glycogen is also selectively depleted from ST and FT fibres, depending on the intensity and duration of exercise. Muscle glycogen is preferably used from the ST fibres. This is probably related to the low force levels used in cross country skiing and to the greater percentage of ST fibres in the muscles of cross country skiers. During the 50 km World Cup ski-race in Lahti, glycogen was depleted by ~90% from ST and by ~50% from the FT fibres. During the 15 km race glycogen was also more depleted from ST than FT fibres. Measurements have not been taken during sprint skiing but, based on other events, ST and FT fibres are then similarly recruited (Fig. 1.7).

During contractions, signals from peripheral sensors in muscles, joints and tendons are processed and interpreted in the CNS to control the execution of movements and performance. Training exercises create memory engrams of motor performance patterns that are called upon during the next training exercises or race performance.

Every coordinated movement requires the application of forces by agonists, synergists and antagonists. The types of muscle contraction are usually categorized into concentric, isometric (static) and eccentric contractions. The force of contraction depends on muscle length and all joints have an optimal angle at which the muscles crossing the joint produce maximum force. The force also depends on the type of contraction. Force production can be enhanced if the muscle is stretched before shortening (stretch–shortening cycle), and then elastic energy can be stored and utilized. Reflexes are one form of CNS control and muscle spindle and tendon reflexes are used in the storage and use of elastic energy.

Cross country skiing requires thousands of dynamic muscle contractions at 10–25% of the isometric and 20–50% of the dynamic maximum force (at the contraction velocity used during ski-racing) of the corresponding muscles. The forces used during skiing are smaller the longer the skiing distance. Depending on the terrain, the peak force of leg kick during diagonal stride skiing is 2–3 × body weight (1500–2000 N) and the force production times are 100–200 ms. During skating the peak forces are slightly smaller than during diagonal skiing but during the gliding phase a static-type kicking or pushing force is produced and the force production time is longer, 300–800 ms. During uphill diagonal skiing the forces are smaller, force production time is longer and recovery period is shorter than during horizontal skiing.

Poling forces during diagonal skiing and double poling are 100–400 N and force production times 300–400 ms. During fast skiing on flat sections the force production time may be so short that the skier cannot apply his or her force fast enough. Female skiers have 10–20% less force but the force production times are similar to those of men.

Role of the central nervous system

The role of the CNS and the mechanisms behind muscle recruitment are not well known. It is thought that CNS has a memory engram or a 'set point' for different performances, such as $\dot{V}\text{O}_{2\text{max}}$ performance or prolonged endurance performance, and muscles are recruited using that engram and set point. The existence of the set point is supported by the fact that at the intensity of maximum oxygen uptake only a fraction (15–30%) of muscle fibres and motor units are recruited at a time. During prolonged high intensity exercise an even smaller fraction of motor units is recruited and the active motor units seem to vary with time so that different motor units within the same muscle are recruited at different times. This variable recruitment allows for distributing the force production to a greater number of motor units which improves fatigue resistance and depletes glycogen from all muscle fibres.

Athletes have 'learned' that it is not wise to recruit more muscles/muscle fibres although they are able to do so. Athletes have also learned to vary the active muscles and muscle fibres within the muscles during endurance performance to prevent fatigue, but at any one time only a 'predetermined' small proportion of muscles/muscle fibres is recruited. Untrained persons who are not used to endurance performances (do not have a well-determined set point) usually start at high speed and then fatigue rapidly. Elite athletes are able to recruit a greater proportion of their muscles during maximal exercise (high fractional utilization of $\dot{V}\text{O}_{2\text{max}}$) and they also have a greater efficiency of performance than untrained or less successful athletes.

It is well known that the CNS controls the preactivation of muscles before ground contact during running. This preactivation has been shown to be greater in high calibre compared to low calibre runners with similar $\dot{V}\text{O}_{2\text{max}}$, when running at the same velocity (Fig. 1.8). As a result, total ground contact time as well as the braking and propulsion phases during contact are shorter even though the relative muscle IEMG activation during the propulsion phase of the contact is lower in high caliper runners compared to low caliper runners having similar aerobic power characteristics. Also, the shorter the contact time the better the distance running performance. The higher preactivation increases muscle stiffness and thereby the ability to store and utilize the stored elastic energy during the stretch–shortening cycle exercises. The ability to store and utilize elastic energy depends on the magnitude of the preactivation by the CNS and on the velocity of the prestretch action. High preactivation and reflex potentiation before and during the initial phase of the muscle contraction increases stiffness and leads to faster transition from braking to propulsion phase. A short braking phase brought about by high preactivation and high stiffness also improves the recoil of elastic energy during the propulsion phase. Therefore, the higher preactivation may explain the ability of high calibre athletes to recruit their muscles more compared to low calibre athletes, and the improved efficiency can in part come from lowered muscular energy use (lower IEMG) during the propulsion phase.

World-class skiers usually have higher peak forces, shorter force production times, more horizontal force production and longer glide length than less

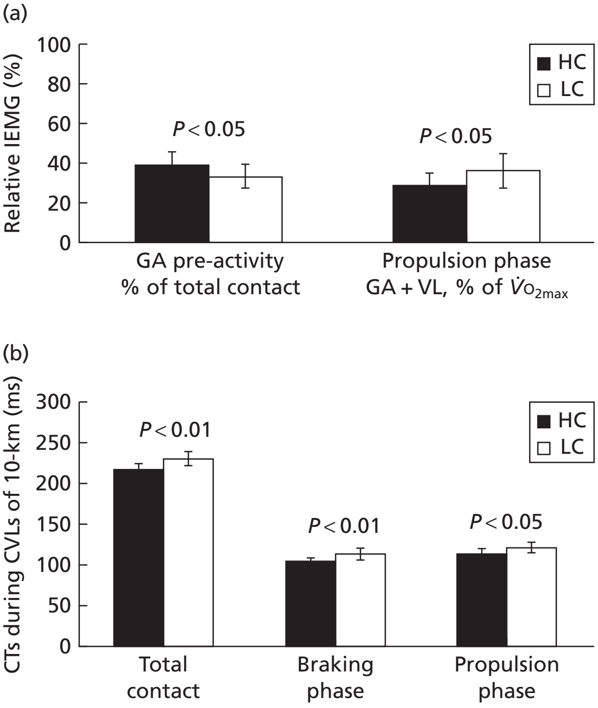


Fig. 1.8 (a) Preactivation phase integrated electromyographic (IEMG) activity is higher and propulsion phase activity is lower. (b) Total contact time as well as braking and propulsion phase times are shorter during constant velocity laps (CVL) of 10 km time trials in high calibre (HC) faster runners as compared to slower runners (LC) with similar aerobic characteristics. (From Paavolainen *et al.* 1999.)

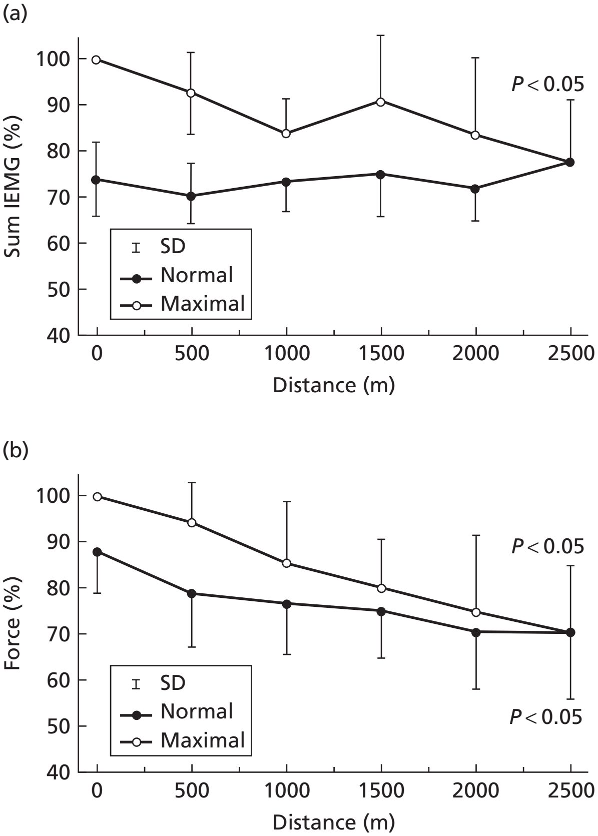


Fig. 1.9 (a) IEMG and (b) force of two maximal strokes (every 500 m) of elite rowers decreased significantly during a 2500-m rowing ergometer test in normoxia. During the normal strokes of the test trial when the athletes themselves regulated the performance intensity, (a) IEMG remained almost unchanged and (b) force decreased. Similar results were found when test trials were carried out in hyperoxia, confirming the important role of the central nervous system as one determinant of endurance performance. (Modified from Peltonen *et al.* 1997.)

successful skiers during diagonal skiing. This is also related to higher preactivation and greater utilization of stretch–shortening cycles including greater storage and utilization of elastic energy in the beginning of the kick. During recent years the storage and utilization of elastic energy has started to be used in skating, when the skiers 'jump' from one ski to another, e.g. during fast uphill skating.

Neuromuscular fatigue resistance

During endurance performance the muscles are fatigued and more IEMG activation and more muscle fibres are needed to keep up the same force level. Recent studies indicate that the ability of the CNS to recruit muscles also decreases. Findings during running and rowing have shown that maximal force and maximal preactivation of muscles decreases during endurance performance (Fig. 1.9). The decrease in maximal force production is related to the decreased maximal recruitment (IEMG) of the muscles. The measurements before and after a 10 km running time trial indicate that contact time (braking and propulsion phases) during maximal 20-m run is increased and preactivation of muscles is decreased. Corresponding measurements have been taken before and after ski-races that also indicate decreased

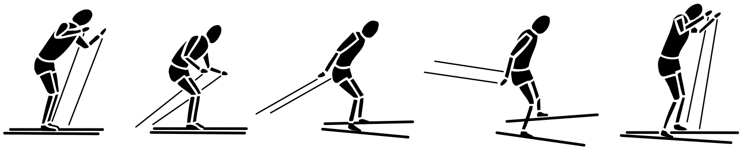


Table 1.6 Percentage decrease in maximal isometric and concentric force and IEMG after long distance ski-race (85 km Wasa-loppet). These results confirm that the maximal ability to produce force as well as muscle recruitment and fast force production ability are decreased during endurance performance, including cross country skiing. (From Viitasalo *et al*. 1982.)

	Percentage change		Significance of change
	Mean	SD	$P <$
Maximal rate of force development	–23	38	0.01
Maximal rate of relaxation	–22	28	0.01
Maximal concentric force	–7	10	0.01
IEMG RF	–65	24	0.001
IEMG VL	–35	26	0.001
IEMG VM	–18	40	0.10
Maximal isometric force	–10	19	0.01
IEMG RF	–51	20	0.001
IEMG VL	–35	20	0.001
IEMG VM	–16	36	0.01

RF, rectus femoris; VL, vastus lateralis; VM, vastus medialis.

maximal force and IEMG activity after the race (Table 1.6).

Fatigue also decreases stride length, probably because of decreased preactivation of muscles, failure in stiffness characteristics, decrease in the velocity of stretch, prolongation of transition time between the braking and propulsion phases and, consequently, the decreased storage and utilization of elastic energy.

Muscle power factors

At the end of the 1980s, the neuromuscular characteristics and so-called muscle power factors were suggested to limit $\dot{V}O_{2max}$ and endurance performance of athletes. Muscle power factors have not been defined but in endurance events they seem to be related to the ability of the neuromuscular system to produce force and power (recruitment of muscles and keeping up the recruitment during the race) when oxygen uptake and/or acidity are high. Acidity is known to impair the contractile function and energy production of muscles. The force production ability starts to be impaired in untrained and sprint-trained athletes when blood lactate concentration approaches the 6–10 $mmol{\cdot}l^{-1}$ level, which is common during cross country skiing. However, cross country skiers are able to keep up their neuromuscular function at higher blood lactate concentration than sprinters (Fig. 1.10). Neuromuscular fatigue is also obvious when lactate is not produced (e.g. Wasa ski-race). The muscle power factors seem to be related to the factors controlling the rate and force of myofibrillar cross bridge cycle activity and calcium removal from cytosol. The maximal power output and efficiency of performance are also related to the elasticity and stretch reflex function of muscles and tendons. The nervous system regulates the muscle stiffness and utilization of elasticity during stretch–shortening exercise, such as the start of the kick and double poling phase during cross country skiing.

In Finland, a treadmill sprint-running test has been developed to measure muscle power factors. The highest 20 s running velocity in an incremental maximal anaerobic running power test (V_{MART}) is used to describe the maximal anaerobic muscle power (AnP_{max}). The MART-test has been described in Chapter 3 (section on Testing for neuromuscular and muscle power characteristics). The MART-test also allows calculation of submaximal indices of anaerobic muscle power, e.g. sprinting velocity at 5 mmol lactate level (V_{5mmol}). V_{MART} has been shown to correlate with fast force production and short contact time during

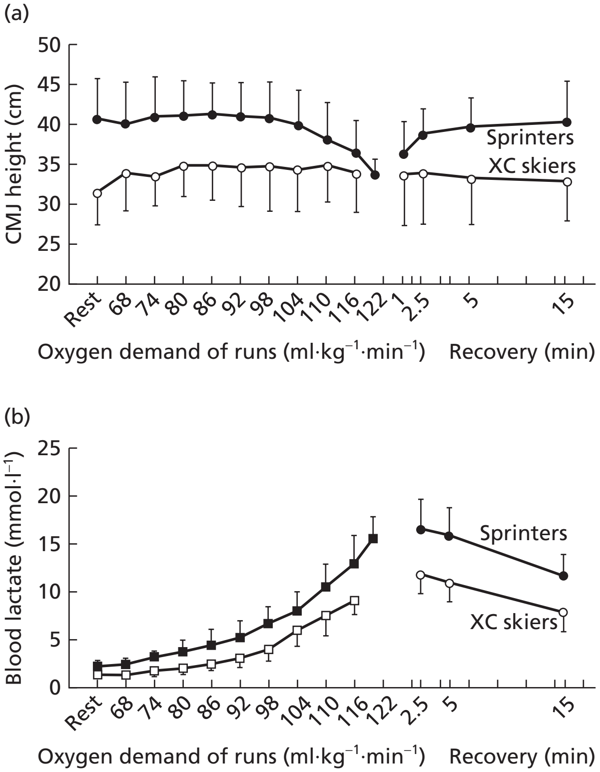


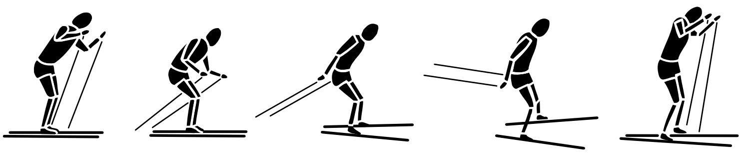
Fig. 1.10 (a) and (b) Counter-movement jump (CMJ) height started to decrease in sprint runners when blood lactate concentration increased above 10 mmol in the maximal anaerobic running test (MART-test, AnP_{max} test). Similarly, CMJ height of cross country skiers also tended to decrease when 10 mmol blood lactate level was approaching. (From Paavolainen *et al.* 1994.)

running and maximal 30 m running velocity as well as with maximal accumulated oxygen deficit and maximal blood lactate concentration, but not with maximum oxygen uptake (Table 1.7). Instead, V_{5mmol} is related to the aerobic components of performance capacity.

Peak velocity ($v\dot{V}O_{2max}$), or power attained during the $\dot{V}O_{2max}$ test on a treadmill, has also been suggested to be a good measure of muscle power factors and a better predictor of endurance performance than $\dot{V}O_{2max}$. This is probably the case because $v\dot{V}O_{2max}$ takes into account the economy of maximal exercise and the neuromuscular and anaerobic factors that influence performance, in addition to the cardiorespiratory determinants of endurance performance. Table 1.7 shows that horizontal running $v\dot{V}O_{2max}$ is related to maximal 30 m running velocity, maximal blood lactate concentration and their combination V_{MART}, but not with $\dot{V}O_{2max}$. Instead, $\dot{V}O_{2max}$ is the most important determinant of uphill running $v\dot{V}O_{2max}$ together with V_{MART}.

V_{MART} in the MART-test has been shown to correlate with 100, 400, 800, 1500, 5000 and 10 000 m running performances on track. Simultaneous explosive strength and endurance training has improved V_{MART}, running economy, maximal 20 m running velocity, 5-jump and 5 km running performance without changes in $\dot{V}O_{2max}$. Interestingly, the changes in 5 km running performance have correlated with the changes in V_{MART} and running economy. The improvements in maximal 20 m velocity and 5-jump

Table 1.7 Determinants of the mean velocity in the 5 and 10 km time trial (V_{5km}, V_{10km}), maximal horizontal ($v\dot{V}O_{2max0}$) and uphill (7°, $v\dot{V}O_{2max7}$) running velocity in a treadmill $\dot{V}O_{2max}$ test, and maximal anaerobic running test (V_{MART}) on a treadmill. Results from runners, triathletes and cross country skiers. (From Paavolainen 1999.)



	$\dot{V}O_{2max}$	RCT	RE_{track}	V_{MART}	$V_{20–30m}$	BLa_{max}
V_{5km}	0.56*	0.74***	0.69**	0.68**	0.63**	n.s.
V_{10km}	0.69***	0.66**	–	–	–	–
$v\dot{V}O_{2max7}$	0.78***	–	–	0.61**	0.53*	0.37
$v\dot{V}O_{2max0}$	0.36	–	–	0.85***	0.78***	0.49*
V_{MART}	0.40	–	−0.62**	1.00	0.87***	0.59*

$*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

did not correlate directly with the improvement in 5 km performance but with the improvements in V_{MART} and running economy (see Chapter 3; for the muscle power characteristics of cross country skiers, see the section on Neuromuscular and muscle power characteristics of skiers).

Main points to remember about Neuromuscular factors

- Fast force production and skilful movement patterns are related to the function of the CNS to recruit muscles.
- Elite athletes have greater preactivation of muscles, indicating the importance of CNS function in determining endurance performance.
- Fatigue of the neuromuscular system includes both the fatigue of muscles and the CNS.
- CNS fatigue during ski-racing and fatigue resistance of the CNS may be more important for superior skiing performance than depletion of glycogen stores.
- Maximal and submaximal anaerobic muscle power is influenced by neuromuscular and anaerobic characteristics and can be used to describe the function of the neuromuscular system during endurance performance.

Limiting factors of skiing performance

In this section the roles of oxygen transport limitation, energetic limitation and neuromuscular limitation are evaluated in the framework of different models for endurance performance.

Oxygen transport limitation

The model of oxygen transport limitation of endurance performance tells us that the main single determinant of endurance performance is maximum oxygen uptake and that in turn is determined by the function of lungs, heart and blood to deliver oxygen to the muscles. This model suggests that with increased exercise intensity, because of limited oxygen supply to the muscles, relative hypoxia develops in the muscles and then muscles start to produce energy increasingly via anaerobic pathways. Concomitantly, lack of oxygen and increased acidity in the muscles set the limits to maximum oxygen uptake and exercise performance (Fig. 1.11).

This model has been supported by studies of training. Endurance training increases stroke volume of the heart, maximal cardiac output, blood volume, oxygen delivery, oxidative enzymes and utilization of oxygen in the muscles which in turn decrease lactate production and lactate accumulation in muscles and blood. Delayed lactate accumulation and decreased acidity then allow muscles to continue contractions at higher intensity than before training.

It is also possible that the limiting organ is the heart muscle. When heart muscle does not attain enough blood/oxygen its contractile function is decreased, or it is unable to increase cardiac output. Interestingly, during maximal exercise in hypoxia or at altitude, maximal cardiac output does not increase to as high a level as in normoxia or in hyperoxia even though the demand for oxygen delivery to the muscles is high and cardiac output during submaximal exercise in hypoxia is significantly increased. The main explanation for the decreased maximal cardiac output is a decreased maximal heart rate while heart rate is increased during submaximal exercise in hypoxia. Why are maximal cardiac output and maximal heart rate decreased in hypoxia when there are no signs of hypoxia/ischaemia in the heart? The low oxygen saturation of blood seems somehow to prevent further increase in cardiac output and heart rate during maximal exercise. Interestingly, animal studies have shown that brain blood flow is increased in hypoxia and during acclimatization cerebral microvascularity is significantly increased suggesting that hypoxia in brain could be the limiting factor.

In many endurance performances oxygen uptake is less than 100% of $\dot{V}O_{2max}$. This is also the case in most cross country ski-races. It is difficult to accept that oxygen delivery alone could limit endurance performance if cardiac output, blood flow and oxygen supply to muscles and oxygen consumption are adequate and not maximal. Athletes with similar maximum oxygen uptake may differ in the fractional utilization of their $\dot{V}O_{2max}$ and in their ability to resist fatigue even though their $\dot{V}O_{2max}$ is the same. The oxidative capacity of muscles is related to fractional utilization of $\dot{V}O_{2max}$ but it is definitely much higher than needed, its explanatory power is small and it is not related to oxygen transport.

This evaluation suggests therefore that while maximum oxygen uptake and cardiorespiratory factors are very important determinants of endurance performance, cross country skiing performance is also limited and determined by other factors.

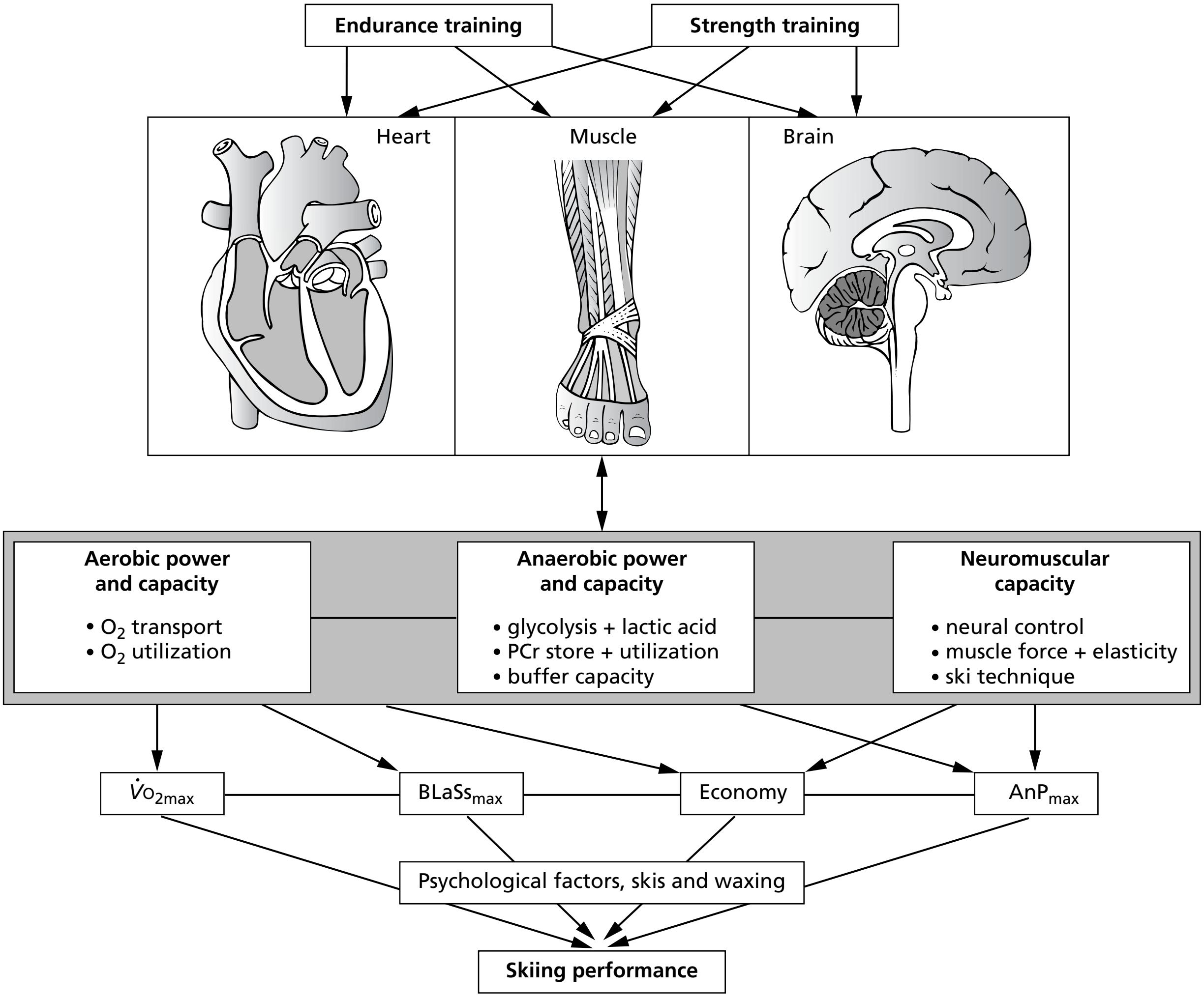


Fig. 1.11 Model of limiting factors of $\dot{V}O_{2max}$ and endurance performance. (Modified from Noakes *et al.* 2001 and Paavolainen *et al.* 1999.)

Energetic limitation

The energetic model proposes that fatigue during high-intensity exercise depends on the inability to supply ATP energy at a sufficiently fast rate to sustain the desired force and power output and therefore the intensity of exercise decreases. In cross country skiing insufficient ATP production could result from using fat oxidation instead of glucose or glycogen breakdown and/or from the inhibition of ATP production (e.g. by acidity) in the muscles. The decreased ATP supply would then limit the performance intensity and/or shorten the time to exhaustion.

The well-known part of this model is related to carbohydrate utilization and glycogen depletion. It is specific for endurance performances lasting for more than 1–2 h and it is based on the observations that:

1 fatigue during prolonged exercise is associated with the depletion of muscle (and liver) glycogen;

2 pre-exercise glycogen supercompensation prolongs the time to exhaustion; and

3 carbohydrate ingestion during race improves performance.

However, in trained athletes fatigue after carbohydrate loading occurs with higher muscle glycogen concentration than without loading and, after adaptation to high-fat low-carbohydrate diet, exercise performance may also be improved and can continue to lower muscle glycogen concentration than before the high-fat diet. During prolonged exercise muscles fatigue even if muscle glycogen stores are not depleted and the blood glucose level is maintained by infusion of glucose. It is also interesting that race performance intensity is not increased with glycogen supercompensation or by using more carbohydrates.

Therefore, a causative relation between carbohydrate utilization, performance intensity and occurrence of fatigue is questionable and it seems that muscle glycogen depletion and low blood glucose cannot be the only determinants of fatigue during prolonged exercise.

Neuromuscular limitation

The neuromuscular/muscle power model suggests that the endurance performance (and $\dot{V}O_{2max}$) are not only limited by oxygen transport and energy supply/depletion but also by the ability of the CNS to recruit muscles. The CNS decides how many muscles are recruited and allowed to produce force and power and thereby regulates the pumping function of the heart. The decision of the CNS is based on information attained from receptors in the heart, arteries, muscles, and probably in some areas of the brain. The maintenance of blood pressure (blood flow) and the oxygen content of blood may be the key regulated variables. When muscles are fatigued more CNS activation (IEMG) is used to keep up the contractile function and force production.

This model has been supported by many studies. In a homogeneous group of endurance athletes other factors (e.g. economy and fractional utilization of $\dot{V}O_{2max}$) seem to be as good or better predictors of performance as $\dot{V}O_{2max}$. It has been shown that anaerobic and neuromuscular characteristics can differentiate homogeneous groups of runners according to their distance running performance and there are similar findings among cross country skiers. Some 'taper' studies have indicated an improvement in endurance performance with reduced training without changes in $\dot{V}O_{2max}$. During tapering the oxidative capacity of muscles decreases but the shortening velocity and power production of muscles and muscle fibres increases. Explosive-type strength training has also improved performance of endurance athletes without changes in $\dot{V}O_{2max}$ (see Chapter 3). Runners attain higher $\dot{V}O_{2max}$ during uphill running than during horizontal running and the closer the horizontal running $\dot{V}O_{2max}$ is to uphill treadmill running $\dot{V}O_{2max}$ the better is the running performance. Preactivation is higher and contact time is shorter in high caliper runners than in low calibre runners. This supports the findings that neuromuscular factors limit the use of the whole potential for oxygen delivery and utilization during horizontal running.

Successful skiers also have better neuromuscular characteristics and maximal anaerobic muscle power compared to less successful skiers (see section on Neuromuscular and muscle power characteristics of skiers). Further, fatigue during endurance performance has been shown to depend not only on energy supply and energy depletion but also on the fatigue resistance of the neuromuscular system.

If this model is accurate it has a significant impact on the theory and methods of endurance training including training for cross country skiing.

Main points to remember about limiting factors of skiing performance

- Endurance performance, such as cross country skiing performance, is not only limited by oxygen transport and $\dot{V}O_{2max}$ but also by neuromuscular factors related to the ability of the CNS to recruit muscles and to the fatigue resistance of the neuromuscular system.
- Irrespective of the limiting factors, maximum oxygen uptake is the most important single determinant of endurance performance.
- The practical message of these physiological models and determinants of endurance performance can be integrated so that the superior skiing performance depends on:
  1. the ability to ski fast—neuromuscular input and muscle recruitment, maximum oxygen uptake, skiing techniques and economy, aerobic and anaerobic energy production; and
  2. the ability to resist fatigue—sustained neuromuscular recruitment, fractional utilization of $\dot{V}O_{2max}$, glycogen stores before and ingestion of glucose during race, utilization of fats, anaerobic and buffer capacity.

Performance characteristics of cross country skiers and skiing performance

The main performance characteristics of cross country skiers are maximum oxygen uptake, the fractional utilization of $\dot{V}O_{2max}$, skiing economy and maximal anaerobic skiing power.

Maximum oxygen uptake of cross country skiers

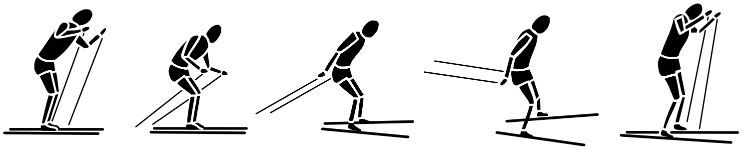
Independent of the different models of endurance performance, $\dot{V}O_{2max}$ is especially important during cross country skiing where large muscle mass is activated and uphill skiing time is highly correlated with ski-race performance. Cross country skiers have always had the highest $\dot{V}O_{2max}$ amongst all endurance athletes. $\dot{V}O_{2max}$ is measured in l·min^{-1} and usually calculated per kg body weight (ml·kg^{-1}·min^{-1}). In cross country skiing the overall importance of l·min^{-1} and ml·kg^{-1}·min^{-1} depends on the profile of the ski-track and on the snow condition and gliding characteristics of the skis. During steep uphill skiing and poor gliding conditions, ml·kg^{-1}·min^{-1} seems to be more important, while l·min^{-1} (and high body mass) is more important on gently inclined uphill sections, on flat terrain and on downhill sections regardless of gliding conditions. In skating, l·min^{-1} may be more critical than ml·kg^{-1}·min^{-1}. It has been calculated that the best index to compare skiers with different body size is $\dot{V}O_{2max}$ divided by body weight raised to the power of 2/3.

Performance and maximum oxygen uptake

During the last few decades the $\dot{V}O_{2max}$ of world-class men and women cross country skiers has increased from 80–85 and 68–75 ml·kg^{-1}·min^{-1} in the 1960–70s, to 90–95 and 73–79 ml·kg^{-1}·min^{-1} in the 1990s, respectively (Table 1.8). The present elite cross country skiers have $\dot{V}O_{2max}$ of 5.5–6.5 l·min^{-1} and the highest individual value has been recorded for a Finnish skier, Juha Mieto, who had a $\dot{V}O_{2max}$ of 7.40 l·min^{-1} in the beginning of his career in 1973 and 7.42 l·min^{-1} in 1985 at the end of his successful career. For elite women skiers the $\dot{V}O_{2max}$ is 4.0–5.0 l·min^{-1} with the highest individual value for Marja-Liisa Hämäläinen-Kirvesniemi of 5.2 l·min^{-1}.

The performance of skiers at international level is related to their $\dot{V}O_{2max}$ (Table 1.9) and several studies have shown that there is a strong correlation between

Table 1.8 Development of $\dot{V}O_{2max}$ of elite skiers from the 1960s to the 1990s in Sweden (from Saltin 1997) and Finland. (From Kantola & Rusko 1985 and H. Rusko unpublished data, mean of 3–5 world-class skiers.)



		1960s	1970s	1980s	1990s	Highest individual value
Male and female Finnish skiers						
Male (ml·kg^{-1}·min^{-1})	Mean		83	84.5	86	93
Female (ml·kg^{-1}·min^{-1})	Mean		73	72	74	78
Difference (ml·kg^{-1}·min^{-1})			20	12.5	12	15
Women/men (%)			77	85	86	84
Male and female Swedish skiers						
Male (ml·kg^{-1}·min^{-1})	Mean	82	85	87	88	
	Range	80–85	82–87	83–90	84–90	
Male (l·min^{-1})	Mean	5.7	6.1	6.3	6.3	
Female (ml·kg^{-1}·min^{-1})	Mean	68	72	71	74	
	Range	64–70	68–76	69–73	68–78	
Female (l·min^{-1})	Mean	3.8	3.9	4.3	4.2	

$\dot{V}\mathrm{O}_{2\max}$ and race performance. The differences in average $\dot{V}\mathrm{O}_{2\max}$ between world-class, medium-class and less successful skiers were only significant when $\dot{V}\mathrm{O}_{2\max}$ was divided by body weight$^{2/3}$. However, the world-class skiers also had greater $\dot{V}\mathrm{O}_{2\max}$ than medium-class or less successful skiers when the l·min^{-1} values were compared, and in male skiers the ml·kg^{-1}·min^{-1} also differentiated between world- and medium-class skiers. The $\dot{V}\mathrm{O}_{2\max}$ of free and classical technique specialists seems to be as high (see Fig. 1.17).

The treadmill uphill ski walking (using ski poles) $\dot{V}\mathrm{O}_{2\max}$ of two Finnish female sprint skiing medallists has been on average 4.4 l·min^{-1} and 71 ml·kg^{-1}·min^{-1} during the summer training period, indicating that sprint skating skiers have as high $\dot{V}\mathrm{O}_{2\max}$ as classical race skiers. Data from the last 2 years are not available from the male national team but the highest $\dot{V}\mathrm{O}_{2\max}$ values of the latest three world champions/Olympic gold medallists during their career have been 89–93 ml·kg^{-1}·min^{-1}. The best values of the three

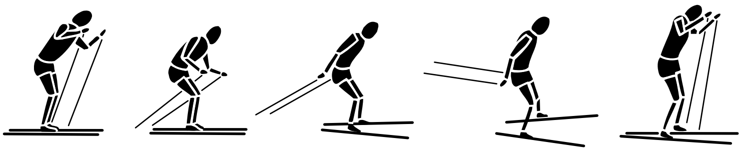


Table 1.9 Maximal oxygen uptake during winter racing season expressed in different units for cross country skiers with different level in World Cup races. (From Ingjer 1991.) Highest recorded values from Finnish gold medallists in Olympic Games or World Championships have been added. (Rusko, unpublished data.)

	Level of skiers			
	World-class	Medium-class	Less successful	Finnish Gold medallists
Men	$n = 13$	$n = 7$	$n = 6$	$n = 3$
l·min^{-1}				
Mean	6.38	5.94	5.74	6.43
Min	5.83	5.50	5.25	
Max	6.57	6.49	6.22	
ml·kg^{-1}·min^{-1}				
Mean	85.6	81.5	79.4	91.6
Min	83.9	78.2	76.0	
Max	88.4	83.7	83.4	
ml·kg$^{2/3}$·min^{-1}				
Mean	355	335	326	368
Min	352	322	316	
Max	359	345	335	
Women	$n = 13$	$n = 6$	$n = 6$	$n = 3$
l·min^{-1}				
Mean	4.28	3.84	3.84	4.61
Min	3.96	3.51	3.45	
Max	4.56	4.16	4.27	
ml·kg^{-1}·min^{-1}				
Mean	70.1	70.6	64.2	74.3
Min	69.0	66.8	60.8	
Max	73.1	74.9	66.9	
ml·kg$^{2/3}$·min^{-1}				
Mean	274	264	248	289
Min	272	252	238	
Max	276	277	257	

latest female Olympic gold medallists from Finland are shown in Table 1.9.

Muscle mass and upper body $\dot{V}\text{O}_{2\text{max}}$

During double poling the active muscle mass is smaller than during diagonal skiing or ski-skating and the amount of upper body muscle mass varies considerably between skiers. The use of double poling with and without kick has become more popular at the expense of diagonal skiing because of better skis, gliding waxes and ski-tracks. During free technique skiing double poling is always used in both V1 and V2 skating. The forward propulsive forces during double poling are great and, consequently, the importance of arm and trunk muscles and upper body $\dot{V}\text{O}_{2\text{max}}$ have increased during the last 10–15 years. The introduction of roller skis in dry-land training and the inclusion of on-snow ski-training camps in the mountains during the summer training season have also improved the upper body $\dot{V}\text{O}_{2\text{max}}$ of skiers. Consequently, the upper body $\dot{V}\text{O}_{2\text{max}}$ has approached the whole body $\dot{V}\text{O}_{2\text{max}}$ concomitantly with the increase in the upper body muscle mass. The highest values for men and women skiers on the double poling ergometer have been 70–75 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and 60–65 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. However, world-class sprint skiers seem to have slightly higher upper body $\dot{V}\text{O}_{2\text{max}}$; the two female Finnish sprint race medallists in Lahti World Championships 2001 had upper body $\dot{V}\text{O}_{2\text{max}}$ of 65–68 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ during roller skating on an indoor horizontal track (see also section on $\dot{V}\text{O}_{2\text{max}}$ using different skiing techniques). The ratio between upper and lower body $\dot{V}\text{O}_{2\text{max}}$ has been found to increase slowly so that at present the upper body $\dot{V}\text{O}_{2\text{max}}$ is about 90% of $\dot{V}\text{O}_{2\text{max}}$ of the lower body in both male and female skiers. Again, the two female sprint medallists mentioned above had values of over 90% during the summer training period. Some elite male skiers also had upper body $\dot{V}\text{O}_{2\text{max}}$ close to 80 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and the ratio between upper and lower body $\dot{V}\text{O}_{2\text{max}}$ was 95%. Very high correlations (ranging from 0.60 to 0.89) have also been observed between upper body $\dot{V}\text{O}_{2\text{max}}$ and race performance.

The upper body muscle mass influences not only the upper body $\dot{V}\text{O}_{2\text{max}}$ but also the combined upper and lower body (and skiing) $\dot{V}\text{O}_{2\text{max}}$ (Fig. 1.12). Skiers differ as to the relative strength of their lower and upper body $\dot{V}\text{O}_{2\text{max}}$, and the correlation between upper and lower body $\dot{V}\text{O}_{2\text{max}}$ values is usually quite low. Many skiers could improve their performance by increasing their upper body $\dot{V}\text{O}_{2\text{max}}$ and thereby their combined upper and lower body $\dot{V}\text{O}_{2\text{max}}$.

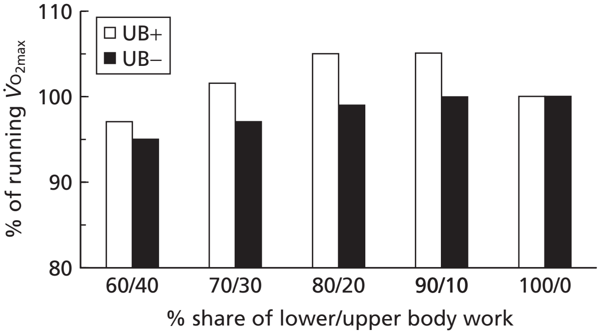


Fig. 1.12 $\dot{V}\text{O}_{2\text{max}}$ during different combinations of arm and leg exercises expressed in percentage of running $\dot{V}\text{O}_{2\text{max}}$ in athletes with high (UB+) or low (UB–) upper body power and muscle mass. (Modified from Kantola & Rusko 1985.)

It has been shown that some skiers attain up to 10% higher $\dot{V}\text{O}_{2\text{max}}$ during uphill skiing on snow and during uphill treadmill ski-striding using ski poles than during treadmill running. Therefore, the amount of active muscle mass is said to limit $\dot{V}\text{O}_{2\text{max}}$. However, when arm exercise is added to leg exercise, blood flow to the leg muscles is decreased and maximal cardiac output is not further elevated and maximal cardiac output is said to limit $\dot{V}\text{O}_{2\text{max}}$. The increase in the $\dot{V}\text{O}_{2\text{max}}$ of elite skiers during the last 20 years, when more combined upper and lower body training has gradually been performed, suggests that both views may be correct. Combined upper and lower body training requires increased oxygen uptake and blood flow in the muscles and higher demands for maximal cardiac output. During training the heart and circulation slowly adapt to these increased requirements.

Development of $\dot{V}\text{O}_{2\text{max}}$ *with age and training*

$\dot{V}\text{O}_{2\text{max}}$ and heart volume are also important determinants of endurance performance of young skiers. Longitudinal studies on young skiers have shown that $\dot{V}\text{O}_{2\text{max}}$ increases with age and training between 15 and 20 years of age, and the annual increase in $\dot{V}\text{O}_{2\text{max}}$

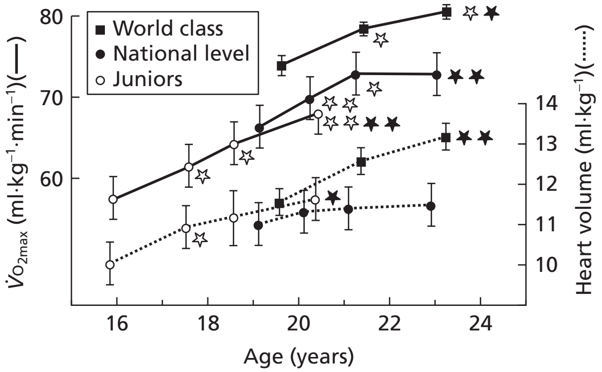


Fig. 1.13 Development of $\dot{V}O_{2max}$ and heart volume with age and training in junior, national- and world-class skiers. ☆ significant changes from preceding value; ★ starting values. $^*P < 0.05$; $^{**}P < 0.01$. (From Rusko 1992.)

amounts to 1–3 ml·kg^{-1}·min^{-1}·year^{-1} (Fig. 1.13). The greatest increase in absolute heart volume and stroke volume occurs during and after the period of most rapid body growth at 14–16 years of age, but the greatest increase in relative heart volume (ml·kg^{-1} body weight) occurs after puberty at between 16 and 20 years of age. After the age of 18–20 years the relative heart volume, and after the age of 20–22 years the $\dot{V}O_{2max}$, start to level off in less successful skiers. However, skiers who have attained world-class level have been able to increase both their $\dot{V}O_{2max}$ and relative heart volume after the age of 20–22 years concomitantly with the increase in their training volume and intensity (Fig. 1.13).

Seasonal changes in $\dot{V}O_{2max}$ vary between 5 and 15% in young skiers and between 3 and 10% in adult skiers. From summer to autumn the average increase in $\dot{V}O_{2max}$ of adults skiers is 1–4 ml·kg^{-1}·min^{-1} and from autumn to winter a further increase is of 2–5 ml·kg^{-1}·min^{-1}. Interestingly, many skiers have difficulty in increasing their $\dot{V}O_{2max}$ during the first weeks of skiing on snow despite a huge amount of skiing training activating large muscle groups (see Table 3.5). The world-class skiers are able to increase their $\dot{V}O_{2max}$ more than less successful skiers from summer to winter. The seasonal changes in upper body $\dot{V}O_{2max}$ are in the order of 5–20% (Table 1.10).

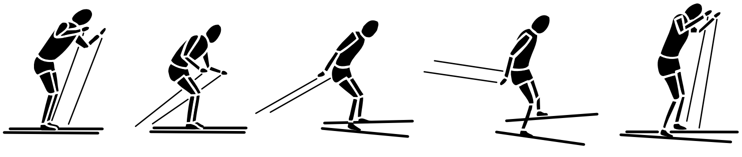
Main points to remember about maximum oxygen uptake of cross country skiers

- When comparing skiers with different body size, $\dot{V}O_{2max}$ is divided by body weight raised to the power of 2/3.
- Maximal oxygen uptake of world-class male and female cross country skiers is 85–95 and 70–80 ml·kg^{-1}·min^{-1}, and 350–360 and 270–290 ml·kg$^{2/3}$·min^{-1}, respectively, and sprint skiers have as high $\dot{V}O_{2max}$ as other skiers.
- The highest values for men and women skiers on the double poling ergometer have been 70–75 ml·kg^{-1}·min^{-1} and 60–65 ml·kg^{-1}·min^{-1}, respectively, and sprint skiers seem to have the highest upper body $\dot{V}O_{2max}$.
- World-class skiers are able to increase their $\dot{V}O_{2max}$ and heart volume significantly after 20–22 years of age.

Fractional utilization of $\dot{V}O_{2max}$, maximal lactate steady state

During heavy exercise, lasting for more than 10–15 min before exhaustion, oxygen uptake is close to 100% of $\dot{V}O_{2max}$. During 15, 30 and 50 km ski-races the fractional utilization of $\dot{V}O_{2max}$ is 95, 90 and 85%,

Table 1.10 The mean percentage seasonal changes from spring to winter in lower and upper body $\dot{V}O_{2max}$, SDH activity in vastus lateralis muscle (mVL) as well as in maximal isometric leg strength and vertical velocity (v$\dot{V}$) in the Margaria test. (From Rusko 1976.)



	$\dot{V}O_{2max}$ running	$\dot{V}O_{2max}$ arm ergometer	SDH activity mVL	V_v	Max isometric leg strength
Male skiers (%)	4.7	5.6	32	2.5	2.3
Female skiers (%)	6.7	6.7	40	7.3	20
Junior male skiers (%)	9.9	17.0	–	1.9	17

respectively (Table 1.3). Therefore, in most cross country ski-races the skiers must be able to sustain as high a proportion of their $\dot{V}O_{2max}$ as possible.

During prolonged exercise, a steady state is attained between lactate production and removal of lactate at the whole body level. The maximal lactate steady state ($BLaSs_{max}$) has been defined as the highest intensity of exercise during which a plateau in blood lactate concentration (Bla ± 0.5–1.0 $mmol \cdot l^{-1}$) lasting for at least 20 min can be obtained. BLa at $BLaSs_{max}$ is on the average 3–4 $mmol \cdot l^{-1}$ higher than resting BLa but the individual values range from 1.5 to 7 $mmol \cdot l^{-1}$ higher than resting level. Because very few data are available on $BLaSs_{max}$ of elite athletes, the information on fractional utilization of $\dot{V}O_{2max}$ is mainly based on so-called 'threshold' studies.

Lactate and respiratory compensation thresholds (aerobic and anaerobic thresholds)

During incremental exercise to exhaustion, blood lactate concentration and some respiratory parameters change in a curvilinear fashion when compared with increases in oxygen uptake or exercise intensity (see Chapter 3, section on Control of training).

Recent studies have shown that there are no exact thresholds during incremental exercise to exhaustion for either blood lactate or respiratory parameters. However, the exercise intensity associated with the beginning of blood lactate accumulation (lactate threshold, LT) and another higher intensity that is associated with the beginning of accelerated ventilatory responses during incremental exercise (respiratory compensation threshold, RCT) have been calculated and used for the description of the fractional utilization of $\dot{V}O_{2max}$ and for the prescription and control of training intensities.

These thresholds have been defined in Chapter 3 (section on Control of training). The LT is defined as the starting point of blood lactate accumulation (0.5–1.0 mmol increase) above blood lactate level at rest. The RCT is defined as the starting point of accelerated CO_2 output and ventilation and decreased end-tidal CO_2 concentration in relation to O_2 uptake when exercise intensity is further increased above LT. In previous literature the terms aerobic threshold and anaerobic threshold have also been used which correspond approximately to LT and RCT, respectively. RCT intensity also corresponds quite well with the starting point of accelerated blood lactate accumulation at about 4 $mmol \cdot l^{-1}$ individual blood lactate level (e.g. onset of blood lactate accumulation, OBLA; individual anaerobic threshold, IAT).

$BLaSs_{max}$ correlates well with both the LT and RCT. The exercise intensity at $BLaSs_{max}$ and RCT are usually similar, allowing the estimation of the fractional utilization of $\dot{V}O_{2max}$ using RCT determination during a single incremental exercise test to exhaustion (depending on the incremental exercise test protocol used for RCT determination). During lower body exercise, the 'anaerobic threshold' is 85–90% of $\dot{V}O_{2max}$ and during upper body exercise 80–85% of upper body $\dot{V}O_{2max}$; these percentage values do not seem to be related to each other.

Determinants of $BLaSs_{max}$ and thresholds

The parameters describing the fractional utilization of $\dot{V}O_{2max}$ correlate with the percentage of ST muscle fibres and the oxidative capacity of muscles, but in female skiers the role of muscle fibre composition is not as great as in male skiers. Blood lactate concentration and threshold variables also depend on diet and substrate utilization, catecholaminergic stimulation, oxygen availability, balance between glycolytic and oxidative enzyme activities and many other factors. The vast number of factors that influence the behaviour of lactate confirms that it is difficult to measure any exact thresholds using an incremental exercise test to exhaustion. The turnover of lactate is one of the main factors behind the high fractional utilization of $\dot{V}O_{2max}$ during prolonged ski-races. In elite skiers, the elimination of lactate from blood seems to be highest (1–1.2 $mmol \cdot l^{-1} \cdot min^{-1}$) when exercising at the intensity of RCT 'anaerobic threshold'. The great fractional utilization is probably also related to the recruitment of muscles and neuromuscular fatigue resistance (Fig. 1.14).

Development of the fractional utilization of $\dot{V}O_{2max}$ with age and training

During prolonged ski-races (30–50 km) the fractional utilization of $\dot{V}O_{2max}$ seems to set the mean intensity of skiing. Normally, athletes who have high $\dot{V}O_{2max}$ also have high $BLaSs_{max}$ and fractional utilization of

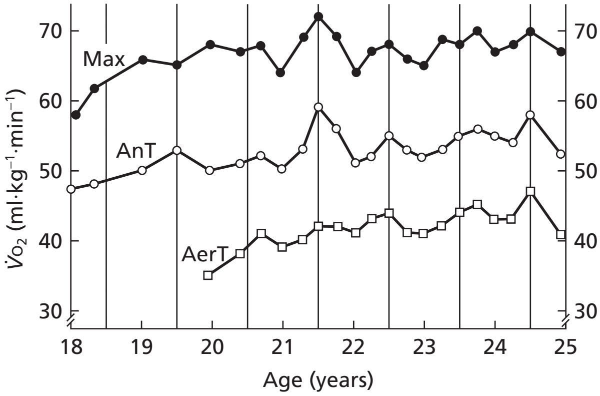


Fig. 1.14 Longitudinal development of $\dot{V}O_{2max}$, respiratory compensation threshold (~ AnT) and lactate threshold (~ AerT) of a world-class female skier. (Rusko, unpublished data.)

$\dot{V}O_{2max}$. The differences in the fractional utilization of $\dot{V}O_{2max}$ between elite cross country skiers are small, indicating that the differences in endurance performance are mainly a function of $\dot{V}O_{2max}$. Some young skiers may have almost as high 'thresholds' in percentage of $\dot{V}O_{2max}$ as adult skiers. However, young skiers are not able to sustain that high percentage during the whole ski-race as well as adult or world-class skiers, indicating that the role of the fractional utilization of $\dot{V}O_{2max}$ during 30 and 50 km ski-races cannot be underestimated.

Longitudinal individual data (Fig. 1.14) and a 4-year follow-up of cross country skiers have shown that threshold values increase slowly with the increase in training volume and that world-class cross country skiers have slightly higher threshold (and maximal lactate steady state) values than less successful skiers. Measurements obtained in the Vuokatti ski-tunnel during skiing on snow have also confirmed that elite skiers are able to use a greater percentage of $\dot{V}O_{2max}$ during fast skiing, explaining the differences between performance level of skiers with almost similar skiing $\dot{V}O_{2max}$.

Main points to remember about functional utilization of $\dot{V}O_{2max}$

- The fractional utilization of $\dot{V}O_{2max}$ is influenced by many factors related to lactate production, removal of lactate from blood and on blood lactate concentration.
- The importance of fractional utilization of $\dot{V}O_{2max}$ is less than that of $\dot{V}O_{2max}$ as shown by the large differences in $\dot{V}O_{2max}$ and small differences in percentage $\dot{V}O_{2max}$ between untrained persons, junior endurance athletes and world-class cross country skiers.
- Young skiers cannot sustain as high a percentage of $\dot{V}O_{2max}$ during prolonged exercise or ski-racing as world-class skiers, even though their threshold values are the same.
- World-class skiers use a slightly higher percentage of their $\dot{V}O_{2max}$ during prolonged exercise and during fast skiing than less successful skiers.
- Blood lactate concentration at the intensity of maximal lactate steady state can range individually from 2 to 8 mmol·l^{-1}.

Skiing economy and comparison of different skiing techniques

Mechanical efficiency is defined as the relation between mechanical work carried out and energy expended. Mechanical work consists of potential, kinetic and rotational work and in cross country skiing the energy expenditure depends on air resistance, the friction between skis and snow, the elevation of the body mass during uphill skiing and during each stride while skiing on horizontal terrain and on the acceleration of different body segments and the centre of mass during each stride (see Chapter 2). In cross country skiing, the mechanical work done is very difficult to measure and the energy expended varies all the time according to the terrain, skiing velocity and snow conditions. The mechanical efficiency of skiing is therefore calculated as the economy of skiing: the oxygen uptake during skiing at a defined submaximal velocity.

Economy of different skiing techniques

From results obtained from studies of runners, the economy varies considerably even within experienced runners and running performance can be predicted quite accurately from $\dot{V}O_{2max}$, running economy and fractional utilization of $\dot{V}O_{2max}$ during the run. In cross country skiing, the differences in economy are purported to be greater than in running because of the greater demand on technique and the necessary skill to use different skiing techniques according to the terrain. In addition, the selection of skis and waxing (weather, snow and gliding conditions) may have a greater effect on the economy than skiing using a single skiing technique.

The few attempts to measure the mechanical work and efficiency of skiing indicate that mechanical efficiency is about 21% during uphill skiing. There are great individual differences in the economy of skiing, but with age and training the economy improves and individual differences become smaller. The small differences in race velocity in skiers with almost similar $\dot{V}O_{2max}$ support this conclusion.

The faster skiing velocities of freestyle races suggest that ski-skating techniques in general are more economical than classical techniques. This has also been shown by oxygen uptake measurements during skiing on snow and during roller skiing. The diagonal stride technique induces greater oxygen uptake than ski-skating techniques and double poling without kick is the most economical technique at a given submaximal velocity on flat terrain or on gently sloped uphill, and kick double poling is as economical as skating. However, few measurements at race velocities and on steeper uphills have been obtained and so conclusions cannot be drawn. Based on indirect evidence of skiing velocities and some oxygen uptake measurements, the economy of ski-skating and diagonal stride skiing are similar during steep uphill skiing. They may both be more economical than double poling on steeper uphill at race velocities, and ski-skating without poling is more economical than double poling on flat terrain at race velocities when gliding conditions are good (see Figs 1.16 and 3.13).

Studies of elite runners also show that mechanical efficiency and running economy are optimal at slow running velocities close to the lactate and respiratory compensation thresholds; at race pace the energy expended per metre is significantly increased (Fig. 1.15). Measurements obtained during classical skiing indicate the same; economy decreases when velocity is increased but during skating the economy remains unchanged with velocity increase (Fig. 1.16).

Because double poling involves less muscle mass than does diagonal stride skiing or ski-skating, the active muscles are relatively more activated during double poling. Therefore, despite the higher economy, blood lactate concentration is higher during double poling than during diagonal or freestyle skiing on gently sloped uphill at a given submaximal velocity (Fig. 3.13).

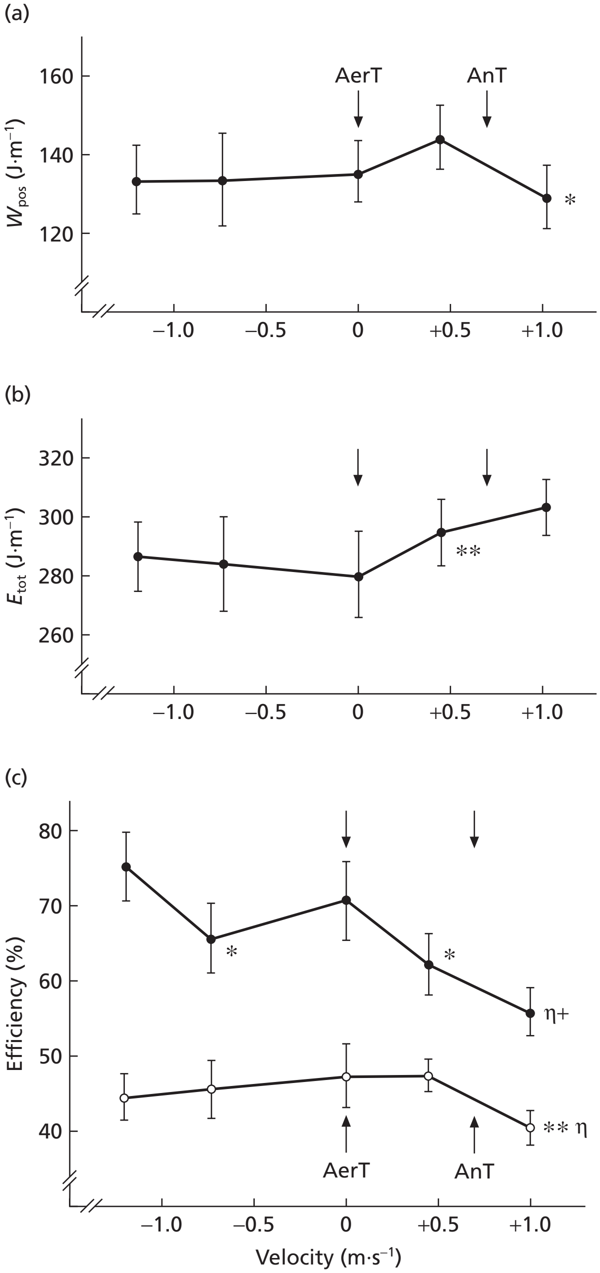


Fig. 1.15 Mechanical efficiency and economy during running are best at low velocity close to lactate threshold (aerobic threshold, AerT) and are significantly impaired at velocities above respiratory compensation threshold (anaerobic threshold, AnT) close to race pace velocity in 1500–10 000 m runners. W_{pos}, positive work·m^{-1}; E_{tot}, total energy cost·m^{-1}; η, gross mechanical efficiency; η+, mechanical net efficiency of positive work. (From Luhtanen *et al*. 1990.)

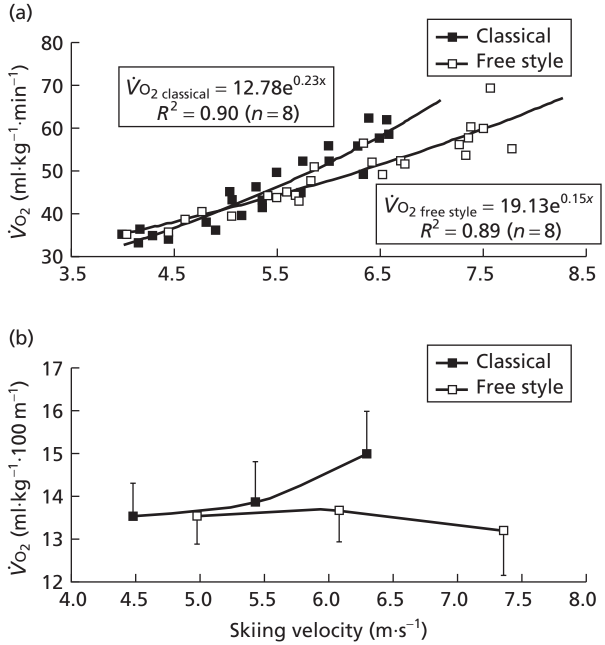


Fig. 1.16 The economy of classical and freestyle cross country skiing at three skiing velocities corresponding to lactate threshold, respiratory compensation threshold and race pace. (a) Economy as $\dot{V}O_2$ at different velocities. (b) Economy as $\dot{V}O_2$ per 100 m at different velocities. Data from eight male junior skiers racing at national level. (From Hynynen 1999.)

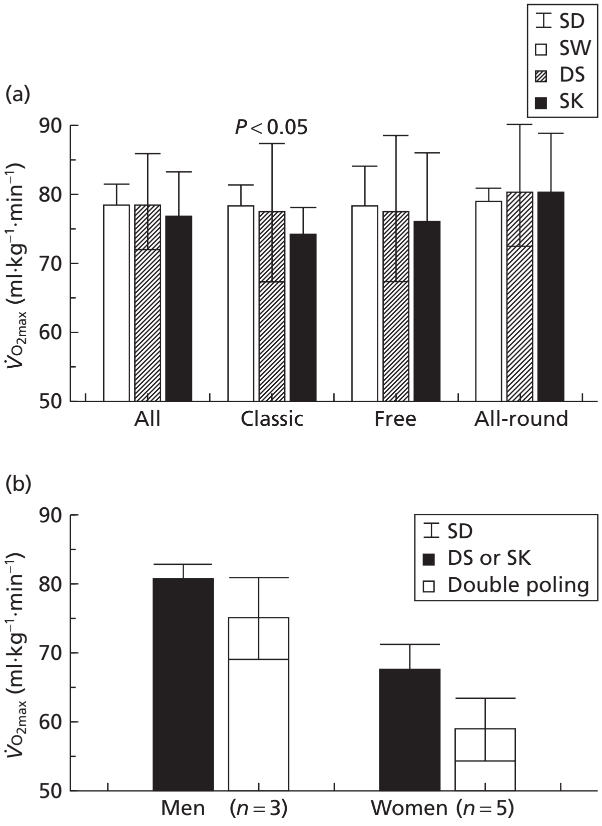


Fig. 1.17 (a) $\dot{V}O_{2max}$ during uphill ski-walking on a treadmill (SW), diagonal stride skiing on snow (DS) and ski-skating on snow (SK) in Finnish national team skiers specialized in either classical ($n = 5$), freestyle ($n = 5$) or all-round skiing ($n = 5$). (Modified from Rusko 1992.) (b) $\dot{V}O_{2max}$ of Finnish national team male ($n = 3$) and female ($n = 5$) skiers during skating or diagonal skiing on snow and $\dot{V}O_{2peak}$ during double poling on snow in the ski-tunnel of Vuokatti Sports Institute, Finland. Double poling $\dot{V}O_{2peak}$ was 88 and 93% of skating or diagonal skiing $\dot{V}O_{2max}$ of male and female skiers, respectively. (Rusko, unpublished data.)

$\dot{V}O_{2max}$ *using different skiing techniques*

During maximal uphill skiing on snow the oxygen uptake is the same as during maximal uphill ski-walking on a treadmill using ski poles (Fig. 1.17). However, there is a tendency to lower $\dot{V}O_{2max}$ during uphill skating than during uphill diagonal skiing. Skiers specializing in classical techniques have attained the same $\dot{V}O_{2max}$ during uphill diagonal skiing as during ski-walking with ski poles on a treadmill, but during uphill ski-skating their $\dot{V}O_{2max}$ was 0.3 l·min^{-1} less. Specialists in freestyle skiing attained the highest $\dot{V}O_{2max}$ during ski-walking on a treadmill, 0.1 l·min^{-1} less $\dot{V}O_{2max}$ during uphill diagonal skiing and 0.2 l·min^{-1} less $\dot{V}O_{2max}$ during uphill ski-skating. All-round skiers attained a similar $\dot{V}O_{2max}$ for each exercise. The lower $\dot{V}O_{2max}$ during skating and leg muscle oxygen saturation measurements indicate that the blood flow to leg muscles is decreased because of the static-type muscle contractions during ski-skating. These findings also indicate that high $\dot{V}O_{2max}$ is a very important determinant of performance in both classical and freestyle ski races and that specialists in freestyle skiing should probably use both freestyle and classical skiing techniques during ski-training on snow in order to attain their high $\dot{V}O_{2max}$ during ski-skating races.

The new ski-tunnel in the Vuokatti Sports Institute, Finland, has made it possible to obtain measurements during skiing on snow more easily. The track is 1600 m long and includes only gently sloping uphills.

The ski-tunnel studies on the Finnish national ski team show that $\dot{V}O_{2max}$ during double poling is 88% (60 ml·kg^{-1}·min^{-1}) and 93% (75 ml·kg^{-1}·min^{-1}) of the diagonal or skating $\dot{V}O_{2max}$ of female (68 ml·kg^{-1}·min^{-1}) and male (81 ml·kg^{-1}·min^{-1}) skiers, respectively, during the summer ski-training period. On average, both female (~10.2 mmol·l^{-1}) and male (~11.1 mmol·l^{-1}) skiers attained similar blood lactate concentration during double poling and skating, but female skiers tended to have lower maximal heart rate during double poling (172 vs. 177 b.p.m.) than during skating. These data suggest that the Finnish female skiers still had the potential to increase their upper body muscle mass, and to improve their upper body muscle strength and muscle power.

During an experimental ski-race the fractional utilization of $\dot{V}O_{2max}$ of the Danish ski team members varied from 82% during double poling and skating without poles on the flat to 94% during diagonal uphill skating (Table 1.11). However, during the actual race the world-class skiers utilized 100% of their $\dot{V}O_{2max}$ during uphill skiing because the oxygen demand was calculated to be higher than their $\dot{V}O_{2max}$.

Main points to remember about skiing economy

- Comparison of skiing economy between skiers is impossible because weather and ski gliding conditions vary so much and influence oxygen uptake measurements.
- Economy is usually better at lower velocity (training velocity) than at race pace.
- Diagonal stride technique is less economical than ski-skating techniques and double poling without kick is the most economical technique on flat and gently sloped uphill sections.
- Diagonal skiing and skating are as economical during steep uphill skiing and $\dot{V}O_{2max}$ is as high.
- $\dot{V}O_{2max}$ is a very important determinant of performance in both classical and freestyle ski races.

Table 1.11 Relative oxygen uptake (percentage of $\dot{V}O_{2max}$) for international elite junior skiers when using different skiing techniques. (From Mygind *et al.* 1994.)

	Classical	Skating	Double poling	Skating, no poles
Horizontal	88–90	89–95	82	82
Uphill	94	90–93	87	85

Neuromuscular and muscle power characteristics of skiers

Muscle strength

The maximal isometric leg force of skiers is almost similar to that of untrained persons and physical education students, but fatigue resistance and ability to produce force rapidly may be more important. Fast force production is especially important during diagonal skiing and during double poling at high velocity because the time to apply the force is very short. Interestingly, cross country skiers are able to produce force almost at the same high velocity as ski jumpers (Fig. 1.18).

Arm and upper body muscle strength of cross country skiers is higher than that of untrained persons and upper body strength has been shown to correlate with double poling performance. Muscular endurance of cross country skiers is also much better than that of untrained persons.

Anaerobic power and capacity

The power of glycolytic and phosphate systems is two- to threefold that of maximal aerobic power which

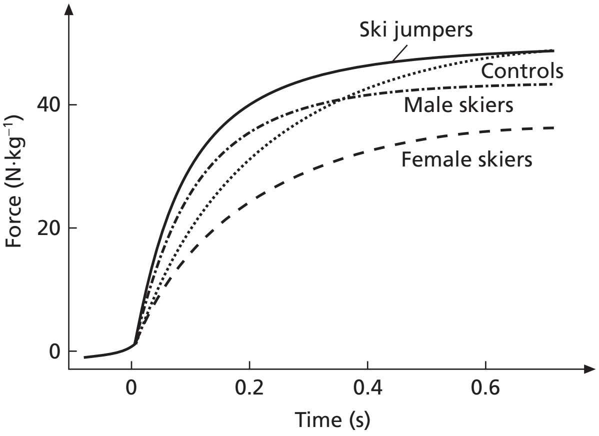


Fig. 1.18 Isometric force–time curve of Finnish national team male and female cross country skiers and ski jumpers and controls (policemen).

indicates that anaerobic power cannot limit the velocity of either traditional or sprint skiing. Instead, anaerobic capacity may limit both the sprint skiing and longer ski-race performances. However, even when blood lactate concentration is 10–20 $\text{mmol}\cdot\text{l}^{-1}$, the share of anaerobic energy production at the intensity of $\dot{V}O_{2max}$ is around 5–10%. At lower intensity (e.g. during longer ski-races) the importance of anaerobic capacity is less and the factors related to fatigue resistance (e.g. removal of lactate from blood) are more important. Sprint skiing requires high anaerobic capacity and high maximum oxygen uptake, even though neuromuscular force–velocity characteristics, good skiing technique and skiing economy are probably the most important characteristics for a good sprint skier.

The anaerobic capacity and maximal blood lactate concentrations of elite cross country skiers are almost similar to that of untrained persons. The maximal blood lactate concentration of the two Finnish female medallists and the male finalist in the Lahti World Championship sprint race were close to the average values for all skiers. However, maximal anaerobic muscle power of cross country skiers is much better than that of untrained persons.

Muscle power—skiing power

A new concept of maximal anaerobic running power has been developed to describe the ability of the neuromuscular system to produce force and power when aerobic and/or anaerobic energy production is high (the measurement of anaerobic muscle power is described in Chapter 3). The need to develop this new concept comes from studies indicating that skiing power during short uphill skiing may correspond to the oxygen demand of 100–120 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ which exceeds the power of the oxygen transport system ($\dot{V}O_{2max}$).

The maximal anaerobic ski striding power (AnP_{max}) of Finnish world-class male cross country skiers has been measured during ski-striding with ski poles on a treadmill and the AnP_{max} values expressed as the oxygen demand of the last 20 s ski-striding performance. The maximal ski-striding performance (AnP_{max}) corresponds to the oxygen demand of 110–150 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ which exceeds the oxygen demand calculated for the short uphill section during the 30-km Olympic ski-race. In the Finnish ski championship pursuit race the AnP_{max} correlated with the race performance and differentiated between successful and less successful skiers with similar maximum oxygen uptake and anaerobic thresholds (Fig. 1.19). In the AnP_{max} test, successful skiers had lower blood lactate concentration during the submaximal 20 s ski-striding periods than the less successful skiers.

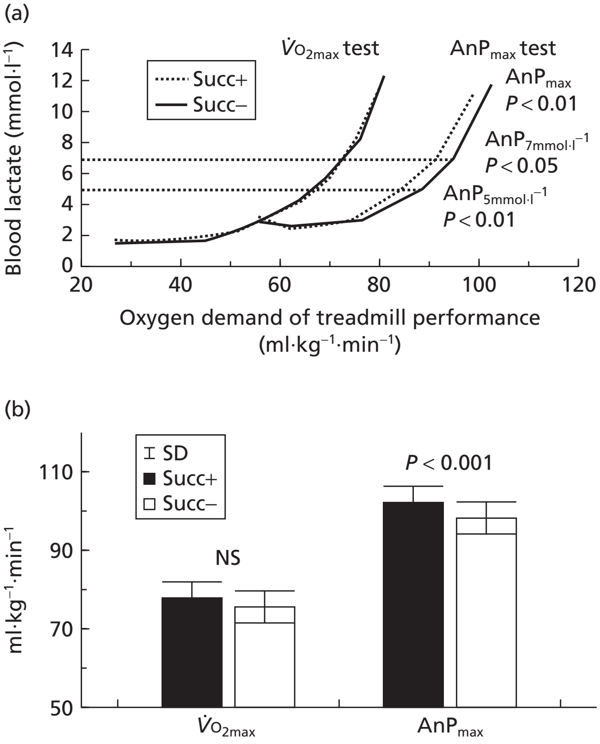


Fig. 1.19 (a) and (b) Blood lactate–exercise intensity curves in the $\dot{V}O_{2max}$ test and maximal anaerobic running power (AnP_{max}) test of successful (Succ +, 10 skiers within the 20 best) and less successful (Succ –, 15 out of the 20 best) cross country skiers in the Finnish championships pursuit race. No significant differences were seen in the $\dot{V}O_{2max}$, threshold values or in the maximal blood lactate concentration between the groups, but the Succ + skiers had significantly better results in the AnP_{max} test at submaximal and maximal exercise intensities. In the AnP_{max} test three 20-s runs were performed at each running velocity. At present only one 20 s pole striding exercise at each exercise intensity is performed (see Chapter 3, section on Testing for neuromuscular and maximal anaerobic skiing power characteristics).

AnP_{max} is especially important during sprint skiing when the energy demand exceeds $\dot{V}O_{2max}$, anaerobic energy is used and the skiing velocity is high. The sprint skier has first to be able to recruit his or her muscles to attain high maximal skiing velocity and then to ski longer at that new velocity and withstand the acidity that develops. Finally, he or she has to improve the economy of skiing at that velocity. The increase of AnP_{max} and maximal skiing velocity gives neuromuscular potential for increasing $\dot{V}O_{2max}$ and related characteristics.

The maximal anaerobic skiing power has also been measured as a maximal skating velocity during incremental sprint ski-skating test on an indoor 200 m track. Female world-class skiers attained a higher maximal sprint skating velocity of $6.6\ m \cdot s^{-1}$ ($n = 5$) than medium-class skiers, $6.1\ m \cdot s^{-1}$ ($n = 5$). Specialists in sprint skiing attained similar maximal velocity in the test as other world-class skiers, but their submaximal anaerobic sprinting velocity at 3 mmol lactate level (calculated from the blood lactate–ski skating velocity curve during the incremental sprint skiing test) was higher ($6.1\ m \cdot s^{-1}$) than that of the other world-class skiers ($5.8\ m \cdot s^{-1}$).

There are also special ski-ergometers that can be used to measure upper body/double poling power. In these tests a 20-s incremental double poling exercise was used, corresponding to the 20–25 s time to ski-skate the 200 m indoor track at maximal velocity. The upper body power of female skiers was only ~ 65% of that of male skiers, indicating that the upper body power of female skiers is much lower than could be expected from their upper body $\dot{V}O_{2max}$, 76–81% of the male skiers. Upper body power has significantly correlated with race performance and with roller skiing $\dot{V}O_{2max}$.

Main points to remember about neuromuscular and muscle power characteristcs

- Skiers most probably have enough maximal muscle strength but they may have limitations in fast force production and in the ability to keep up force production throughout the whole duration of a ski-race.
- Anaerobic capacity is important in the new sprint race but differences in anaerobic capacity as calculated from maximal blood lactate concentration between skiers and untrained persons are small.
- Maximal anaerobic skiing power is an important determinant of skiing performance in all ski-races because oxygen demand may exceed $\dot{V}O_{2max}$ during short uphill and sprint skiing.
- The maximal anaerobic skiing power of skiers is high even though their maximal blood lactate concentration is 'normal', indicating that the neuromuscular factors and the ability to remove the lactate produced during uphill skiing as soon as possible are important determinants of skiing performance.
- Maximal anaerobic muscle power (skiing power) differentiates between successful and less successful skiers with similar maximal oxygen uptake.

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Chapter 2

Biomechanics of cross country skiing

Endurance sports such as running and cross country skiing share many characteristics which make them attractive for alternative season activities. The joy of running forest trails is matched by skiing through the woods on tracks that roll up and down adapting to terrain. Running such trails can be physiologically demanding but involves relatively simple technique. The subtle adjustments of stride length and frequency, of foot placement and arm motion are intuitive and come naturally to most runners. In contrast, skiing such wonderful changing terrain requires a variety of complex techniques smoothly linked together. Both running and cross country skiing demand large metabolic capacities; race results are certainly determined in large part by competitor physiology. However, in skiing, technique and equipment probably have a much greater role in affecting performance than in running. This chapter explores the mechanical side of skiing—looking to explain the subtleties of technique, characteristics which drive performance, interactions of equipment, technique and economy of motion.

To understand the mechanical side of skiing, it is helpful to use the tools that engineers and physicists use for analysis of inanimate systems. Biomechanics applies engineering methods to analysis of human motion; we explore what biomechanics can explain about skiing technique and performance. Mechanics can be broadly divided into two approaches: ‘kinematics’ deals with descriptions of motion using characteristics such as displacement, speed and acceleration while ‘kinetics’ deals with the causes of motion such as force, torque and energy. To understand human motion it is often helpful to start with kinematics so that one can quantitatively ‘picture’ movement patterns. Ultimately, kinetic characteristics are what drive motion and which must be determined to approach understanding of complex movement patterns like those of cross country skiing.

Mechanical principles

While the British are not often thought of as a skiing ‘powerhouse’, performance in skiing is best understood through the observations and insights of the famous non-skiing British scientist Isaac Newton. His contributions to classical physics are well known to any general physics student, but restatement and discussion of these physical ideas in the context of cross country skiing can clarify the fundamental characteristics that affect skiing performance.

Newton’s laws of motion are often memorized as dealing with inertia, acceleration and action–reaction. Important concepts behind these phrases will require some explanation. We keep the skiing context in mind but recognize that the principles generalize to any motion.

Newton’s Law of Inertia

A skier (or any other object) in motion will continue moving in the same direction at the same speed unless some external force (such as gravity or friction) acts to change the motion characteristics. Visualize a skier gliding downhill and then across flat terrain on icy fast tracks. A tail wind blowing behind the skier minimizes air resistance. The skier feels able to glide forever without slowing down. That is inertia. If friction across the snow were really zero and the wind blowing enough to eliminate air resistance, the skier’s motion would in fact continue at the same speed and in the same direction forever! Skiers do not naturally slow down when gliding. It requires external forces such as friction to accomplish that (Fig. 2.1). Newton’s second law, which follows, describes how much an external force affects a skier’s motion.

Newton’s Law of Acceleration: $F = ma$

A force (F) acting on a skier will cause an acceleration (a) of the skier in the direction of the force and proportional to the strength of the force. The acceleration will be inversely proportional to the skier’s mass (m). This relationship, which is so simply summarized in the equation $F = ma$, is perhaps our most important

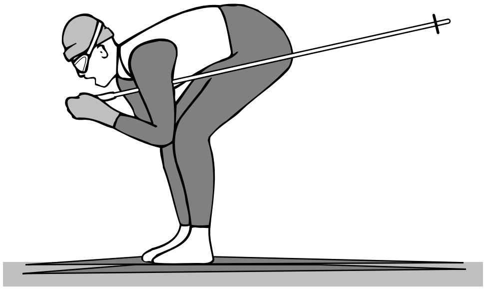

Fig. 2.1 A skier in motion will continue at the same speed and in the same direction unless there are external forces acting: this is the concept of inertia. Gliding across flat terrain if air resistance and friction acting on the skis were zero, a skier would continue moving forever.

tool for understanding skiing mechanics. Revisualize the skier gliding on flat tracks. Friction on the skis is a force acting opposite to the direction of motion. It will cause a decrease of speed, which is often called a negative acceleration or a deceleration. The severity of the deceleration depends on the magnitude of the frictional force and also on the skier's mass.

Now put a strong tail wind back into your picture of the gliding skier. If the wind speed is greater than the skier's speed, it will exert a force pushing the skier from behind. At some speed this 'push' from the tail wind could exactly match the frictional force of skis gliding on snow. What would happen? The two forces are in opposite directions and of the same magnitude or strength. Where the snow frictional forces would decelerate, the tail wind would accelerate; the forces would balance, they would combine to be of no effect. This illustrates a deeper meaning of F = ma. Acceleration of a skier results from *all* the external forces acting; some may cause negative, some positive acceleration. The total force with contributions from all external forces is what matters. In our example, the snow frictional force and the pushing force of the wind are of equal strength and in opposite directions. They combine to zero force. From F = ma, if total external force is zero then acceleration must be zero; the skier will continue gliding along at constant speed. Notice that this is just a different way of getting to the idea of Newton's first law.

Total force is a slightly more complicated idea when the forces acting on a skier are not collinear; that is, not acting in the same direction. Returning to our gliding skier, if the wind was blowing past the skier just as before but from the side instead of from behind, the snow friction and wind force would not combine to be zero. Some more complex combination determining the total force would be acting to change the skier's motion. This requires knowing the directions of all the forces involved and combining them using the mathematical technique of vector addition. This will be described in more detail after introducing Newton's third law.

Newton's Law of Action–Reaction

A skier's push against the snow is matched with a reaction force of equal magnitude but opposite direction of the snow pushing on the skier. Muscle activity and body motion can create forces against the snow ('action' in Newton's terminology). Such actions are *always* paired with reaction forces applied to the skier. Note that these two forces do not 'cancel' each other out as they act on different objects. The action force is applied to the snow and earth (very large mass and small acceleration) while the reaction force is applied to the skier (relatively small mass and substantial acceleration). It is reaction forces which largely determine a skier's performance.

Like other forces, reaction forces are vector quantities. The skier of Fig. 2.2 pushes down through the poles and applies a force against the snow. The snow reaction force is of the same magnitude but aimed up the pole and ultimately to the body through the hand and arm. This reaction force aimed along the pole is composed of two parts: a horizontal component and a vertical component. Together these components make up the 'resultant' reaction force; separately they affect motion in the horizontal and vertical directions. The greater the horizontal component, the greater will be the skier's acceleration in the forward direction. This is called propulsive force. The vertical reaction force component affects motion up and down only and does *nothing* to propel the skier forward.

The relative proportions of the horizontal and vertical reaction forces depend on the angle of the resultant reaction force with respect to horizontal or vertical. In Fig. 2.2 this depends on the pole angle and how inclined it is from vertical. As the pole inclines away from vertical, the horizontal component, the propulsive force, becomes larger while the vertical

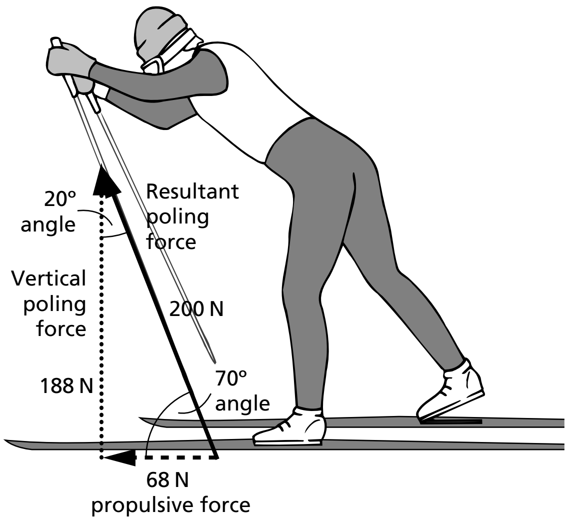

Fig. 2.2 Poling force is a vector quantity. The resultant force is composed of a vertical and a horizontal (propulsive) component. The magnitude of the components depends on the angle of the pole with respect to vertical and horizontal. With a pole angle of 20° from vertical and a 200-N force along the axis of the pole, about 68 N propulsive force [200 × sin (20°)] is generated.

component becomes smaller. This relationship is illustrated in Fig. 2.3 at the beginning and near the end of a poling action.

Forces affecting skiing

Skier-generated reaction forces at the poles and skis are a competitor's primary means of moving down the ski tracks. However, several other forces also affect the motion. Gravity is a large force which is determined by a skier's mass and which is always directed vertically downward. On downhills, a proportion of the gravity force (or weight) of the skier is aimed in the forward direction and acts to propel a skier down the slope. Figure 2.4 illustrates how the steepness of a downhill affects the propulsive component of gravity. In a similar manner on uphills, gravity acts against a skier's forward motion. In either case there is little that a skier can do to change the gravitational force acting to slow or to propel him down the tracks. In contrast, frictional forces of skis on snow and the body passing through air can be affected by skier technique and equipment.

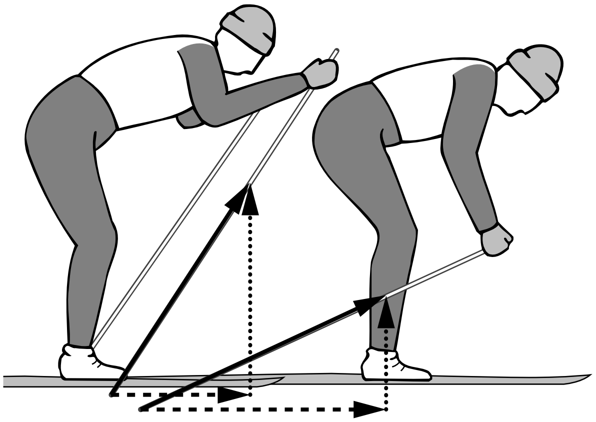

Fig. 2.3 Vertical and propulsive force magnitudes depend on the applied force along the pole and on the pole angle. With the same applied force, as the poles are inclined away from vertical, the proportion of propulsive force increases and poling more effective in propelling the skier forward.

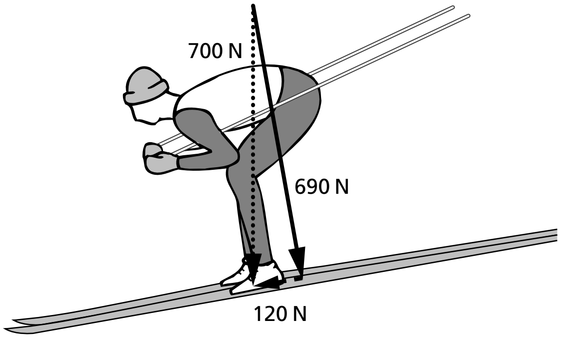

Fig. 2.4 Gravitational force acts to propel a skier downhill. The magnitude of the force depends on the slope. A skier weighing 700 N (mass of about 70 kg) on a 10° downhill has a gravitational force propelling the motion of about 120 N [700 × sin (10°)].

Air resistance or air drag is a complicated force which depends on a skier's shape and size, on the atmospheric pressure, and on the *relative velocity* of air passing the skier. Origins of air drag force are ultimately caused by pressure differences on the front and back of a skier's body, but we need not go into those details here. The tuck position seen in Fig. 2.4 is an effective downhill technique because it streamlines airflow and it minimizes frontal area of the skier. We explore these relationships in more detail later in this

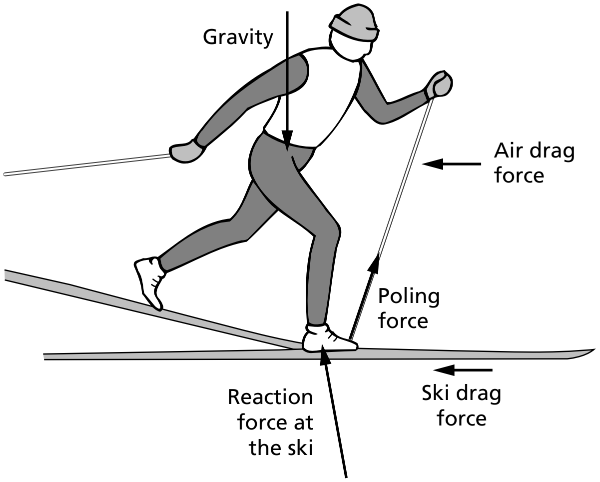

Fig. 2.5 Motion of a skier depends on all the forces acting at any moment in time.

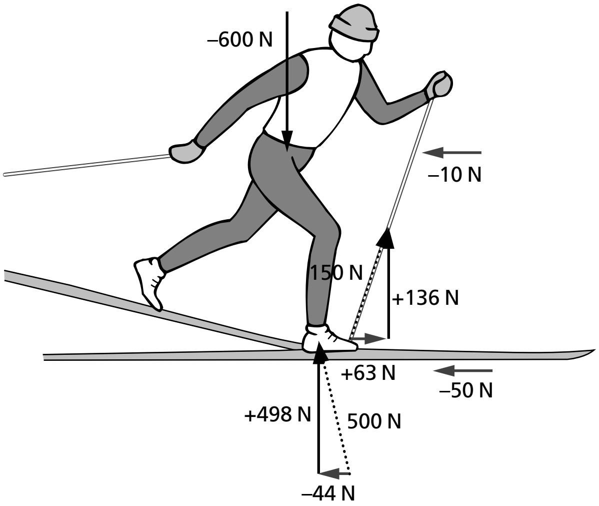

Fig. 2.6 Finding the total effect of all the forces acting on a skier at some moment in time depends on summing all the forces in a vectorial manner. Each component of force must be known and appropriately summed. The plus and minus signs are indicative of the force directions and are conventionally taken to be upward positive, downward negative and to the right positive, to the left negative. Vertical force components are combined and horizontal forces are combined.

chapter. Relative velocity of air passing the skier can be positive or negative in direction as can the air drag force itself. A head wind will cause air drag forces resisting a skier's forward motion while a tail wind blowing faster than a skier's forward motion will help propel that motion. Hence air drag, like gravity, can be propulsive or resistive in direction.

In contrast, snow drag force is always acting against a ski's forward motion. Numerous factors, such as snow conditions, wax, and ski stiffness, affect the magnitude of snow drag force and these are explored in more detail later in this chapter and in other chapters of this book.

This collection of forces we have been describing are illustrated in Fig. 2.5. Newton's second law tells us that it is the total force resulting from adding all the external forces together which determines a skier's motion. Let us estimate each of the forces shown in Fig. 2.5 and see how they combine to determine the skier's acceleration at the moment in time illustrated. The skier shown had a body mass of 60 kg and therefore weighed about 600 N, which is the gravitational force acting vertically downward. Skiing at 5 $\mathrm{m \cdot s^{-1}}$ she had a horizontal air drag force resisting forward motion of about 10 N. Snow drag force depends on the snow–ski coefficient of friction and on the force pressing vertically down on the ski. So let us first determine the reaction force at the ski. Using instrumented skis, reaction forces at the moment illustrated during glide are about 80% of a skier's weight or about 500 N in this case. These various forces are illustrated in Fig. 2.6 where it can be seen that the reaction force is angled slightly backward (about 5° or so from vertical), hence there are horizontal and vertical components of the reaction force. These are proportional to the sine and cosine of the 5° angle with magnitudes shown on the diagram. From the vertical reaction force we can estimate the snow drag force to be about 50 N. Finally, the pole reaction at this point in a stride is about 25% of a skier's weight or about 150 N in this case. With the pole angled forward at about 25° from vertical, horizontal and vertical components of the poling force can also be calculated using the sine and cosine trigonometric functions. The force components shown in Fig. 2.6 can be grouped into those directed horizontally and those directed vertically.

In the horizontal direction if we consider the skier's forward direction as positive, the horizontal pole reaction force is + 63 N while all the other forces are negative: air drag force (– 10 N); snow drag force (– 50 N); ski reaction force (– 44 N). Newton's second law tells us that the sum of these horizontal forces determines the skier's horizontal acceleration at this moment of time. Thus,

$F_{horizontal} = +63 - 10 - 50 - 44 = -41$ N.

Further, knowing that F = ma, we can determine the skier's acceleration at this instant in time,

$a = F/m = -41\ \text{N}/60\ \text{kg} \approx -0.7\ \text{m}\cdot\text{s}^{-1}$.

The skier was slowing down by about 0.7 $\text{m}\cdot\text{s}^{-1}$ per second while gliding on that ski.

In the vertical direction if we consider up to be positive, the ski and pole reactions forces are positive (+ 498 and + 136 N, respectively) while the gravitational force (skier weight) is downward (– 600 N). Again from Newton's second law, the total vertical force will determine the skier's vertical acceleration. Thus,

$F_{vertical} = +498 + 136 - 600\ \text{N} = +34$ N

and from which vertical acceleration is a = F/m = 34 N/60 kg ≈ + 0.6 $\text{m}\cdot\text{s}^{-2}$. The skier had a slight vertical acceleration. Note that this vertical acceleration is independent of the air and snow drag forces which are horizontally directed.

This rather lengthy computational example has applied Newton's laws of motion at a single moment in time to determine the effect of external forces on a skier's motion, but we are interested in much more than such single moments in a stride. To determine the full dynamic stride mechanics would require repeating that process moment by moment throughout the stride based on measurements of the external forces. While such measurements are not easily obtained, instrumentation has been developed to record the reaction forces of skis and poles during skiing. Figure 2.7 illustrates the reaction force patterns for the diagonal stride technique of our previous example. Qualitatively assessing the magnitudes of these reaction forces, relatively low magnitude propulsive forces (y direction in the figure) are observed, except for the brief 'kick' of the ski and during later poling. These brief periods are the only times when skier-generated propulsive force is of greater magnitude than the air and snow drag forces resisting forward motion and the only times during a stride when positive forward acceleration is generated.

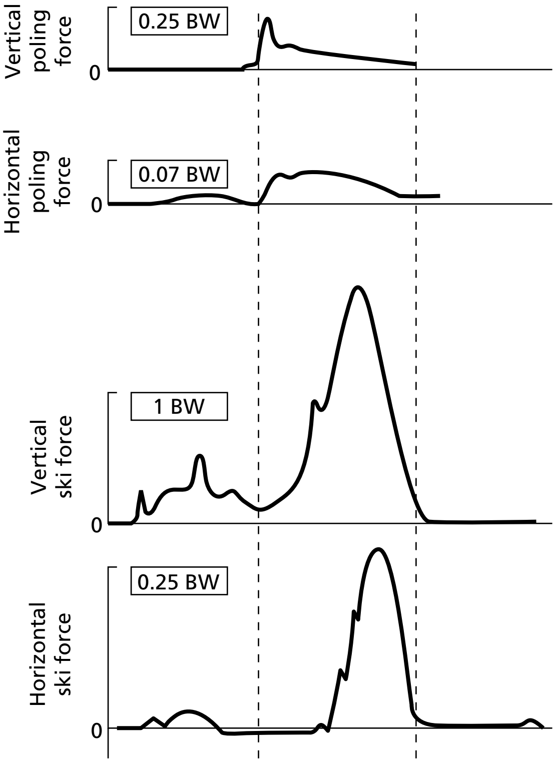

Fig. 2.7 Pole and ski reaction forces during diagonal stride on uphill terrain. Such forces are often expressed in multiples of body weight (BW). So, for example, at pole plant vertical poling force is about 20% of body weight. During kick phase, vertical reaction force at the ski is about twice body weight. (Figure adapted from Komi 1987.)

The motion during diagonal stride used for the previous example and Figs 2.5–2.7 is a relatively planar movement pattern which involves little side-to-side motion. Looking at the arm and leg motions and the forces in the sagittal plane (side view) is a good approximation to the full three-dimensional motion. Thus, the pole and ski reaction forces shown in Fig. 2.7 did not include a component in a side-to-side direction. In contrast, the skating techniques involve considerable side-to-side motion as well as in the other dimensions. To measure the three-dimensional force components during skating requires knowing the direction of the reaction forces in space—a much more difficult determination than for the two-dimensional forces of diagonal stride. Figure 2.8 illustrates this for the pole reaction force resolved into propulsive, vertical and side-to-side

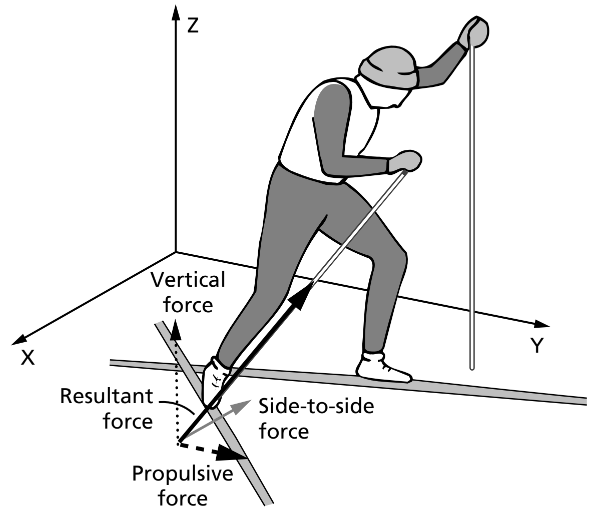

Fig. 2.8 Three-dimensional force components are required to analyse skating kinetics. The components depend on the orientation of the pole in space. This requires two angles to describe and considerably complicates force data collection compared to two-dimensional analysis.

force components and would require knowing the force applied along the axis of the pole and the pole's three-dimensional orientation in space.

The pole orientation illustrated in Fig. 2.8 is commonly observed during some skating techniques and results in a substantial force component in a side-to-side direction as well as vertical and forward directions. As orientation of any of the reaction forces change, the effectiveness in propelling a skier forward will change in proportion to the propulsive component of force. Thus, each pole and ski orientation can influence the effectiveness of reaction forces generated by the skier.

Main points to remember about mechanical principles and skiing

- Newton's laws can be used to understand and to predict how technique, equipment and snow conditions all interact to determine motion.
- Newton's laws tell us that the total force in each of the three-dimensional directions will determine the skier's acceleration in that direction.
- Performance is determined by forward motion, hence those components of reaction force in the forward direction are crucial for a skier to generate and the negative components caused by drag are equally crucial to minimize. However, motion in the other directions is also necessary for many of the ski techniques and cannot be eliminated.
- Total forces acting on a skier (combined from gravity, air and snow drag forces, and skier-generated reaction forces) determine a skier's motion changes.
- Skier-generated propulsive force combined with drag forces against forward motion are the primary mechanical determinants of skier performance.

Kinematics and kinetics of ski techniques

Performance in cross country skiing is determined by the complex interaction of physiology and mechanics. The forces which drive a skier's motion come with metabolic expenses and limitations which affect the ability to generate and sustain force at ideal levels. Optimization in skiing occurs at levels ranging from waxing to equipment, technique, and race pace choices. In any optimization situation there are trade-offs between various operational states which are balanced against each other in a manner that results in the best performance. For example, grip wax choices in classical skiing affect both the static and dynamic frictional characteristics of a ski. A 'slippery' ski will have relatively low snow drag forces when gliding which is an advantage but may allow relatively little propulsive force to be generated by a diagonal stride's kick which is disadvantageous. A stickier wax will have greater snow drag forces but the kick will generate larger propulsive forces. An optimal choice of kick wax balances these characteristics to obtain the best performance. Neither maximal glide nor maximal propulsive kick force will work well; rather, the best wax choice is probably something which allows both moderate glide and kick force. This optimization process occurs on many levels in skiing.

Preceding sections of this chapter have introduced the mechanical principles that affect a skier's motion. Force is the central physical characteristic which ultimately determines skier motion and which is involved in the optimization process. This section discusses both classical and skating technique movement patterns and the forces involved. The reader should keep in mind that for each technique optimization will balance the competing demands of propulsion vs. drag force with physiology playing a limiting part in a skier's ability to generate force.

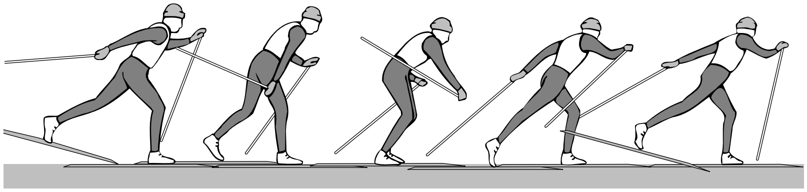

Fig. 2.9 Diagonal stride involves poling and kicking phases. The half cycle illustrated includes a left arm poling phase in the interval between positions 1 and 4 and the brief right leg kick phase between positions 3 and 4. Glide phase on the left ski occurs after position 4 and continues until the next kick phase. The relative proportions of poling, kick and glide phases are adjusted in going from flat to steep uphills.

Classical ski techniques

Part of the optimization process involves skiers directly adjusting technique to match the demands of terrain, snow conditions, wind, metabolic intensity and muscular strength. Numerous optimization decisions take place during the course of a race, but probably the most observable choices have to do with technique. In the classical races, skating is restricted and the primary movement patterns are the mainly two-dimensional motions of diagonal stride, double poling and double poling with a stride or kick (see Figs 2.9, 2.15 and 2.19). These techniques are not interchangeably used. Diagonal stride is mainly a slower conditions technique usually used in climbing and double poling is typically used under fast conditions: moderate downhills and fast flat terrain. Kick double pole is used somewhere in between: moderate conditions on flat or gently uphill. Skiers smoothly transition from one technique to another as terrain and snow dictate. While such changes come naturally and feel appropriate to skiers, the reasons behind technique choices are not obvious and demand both mechanics and physiology to explain. As we systematically discuss the classical techniques, keep in mind this question about optimization of performance and technique choice. Understanding this optimization will require understanding the mechanical characteristics of the techniques.

Diagonal stride

Human locomotion is cyclic in nature and in the most basic patterns of walking and running the arms and legs move in opposition to each other. A full cycle in these cases involves a right and a left step combining into a full stride. The diagonal stride in skiing is closest to these fundamental movement patterns and similarly involves arms and legs working in right–left pairings (Fig. 2.9).

The movement pattern of Fig. 2.9 and the vertical and propulsive components of force shown in Fig. 2.7 represent half of a diagonal stride cycle. This classical technique involves 'kicking' from a momentarily stationary ski onto the other gliding ski, which in the next half cycle slows to a stop allowing the skier to kick from it. During the very brief stationary period of the ski's motion, a large vertical force compresses the mid-section of ski against the snow. With appropriate wax on the ski, the mid-section momentarily sticks to the snow because of the large normal force and high pressure in that region (Fig. 2.10). The static frictional force is large enough during the kicking phase that a brief propulsive component of force in the forward direction can be generated. The magnitude of this force depends on the frictional characteristics during kick. These can vary widely depending on snow conditions, ski stiffness and wax properties (Fig. 2.11). While vertical forces during this kick phase may be two to three times body weight, the propulsive forces are much smaller (approximately 10–25% of body weight) and are of very short duration—about 0.1 s. In contrast, skating forces (discussed below) are applied over a considerably longer time interval.

Generating propulsive force during the kick phase of diagonal stride requires careful timing of the vertical and horizontal forces matched to the glide speed of the ski. As the ski slows to a stop, the large vertical force must quickly compress the cambered mid-section of the ski to the snow surface which momentarily creates a static frictional force. Optimal technique directs the ski reaction force vector at

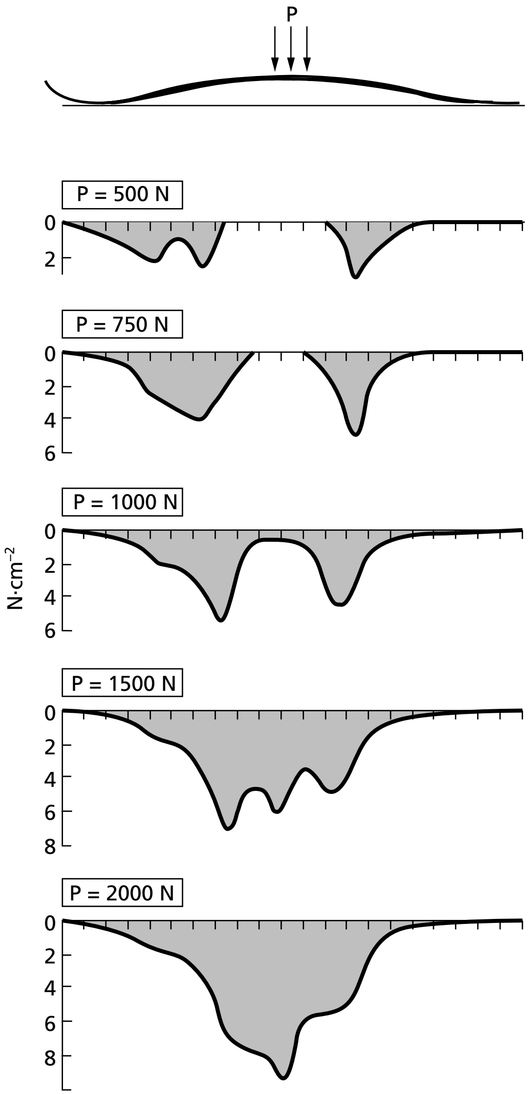

Fig. 2.10 Pressure distribution pattern under a ski depends on the applied force. Under a classical ski, a region of low pressure exists in the middle with moderate vertical forces. However, with greater loading, this mid-region of the ski experiences high pressure. Grip wax placed in this zone has little effect on glide when a ski is weighted moderately but when kicked the wax is pressed firmly into the snow. (Figure reproduced with permission Ekstrom 1981.)

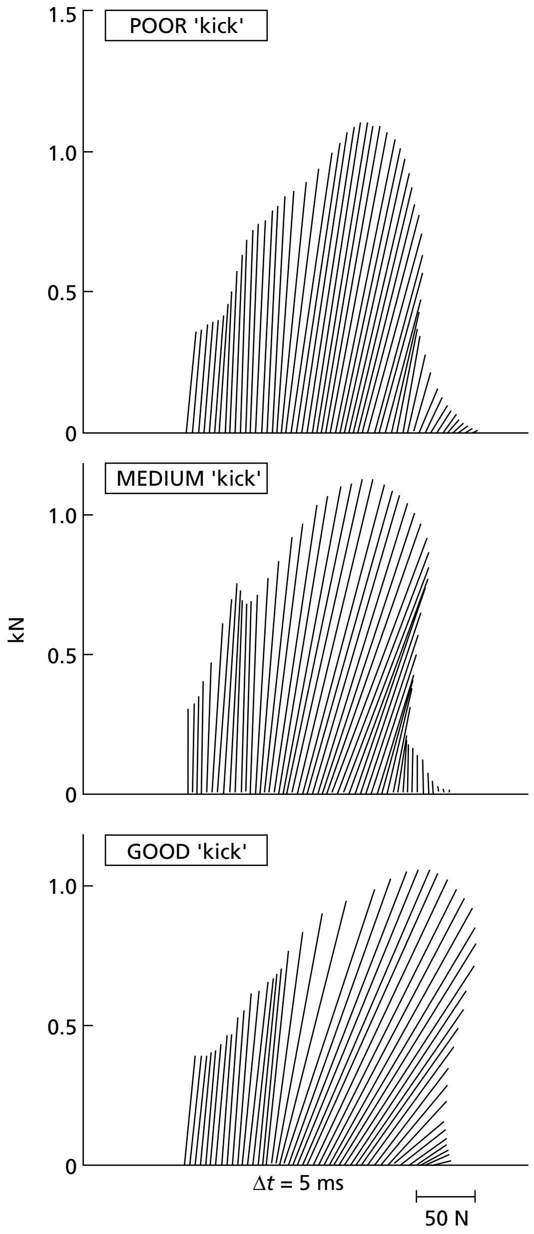

Fig. 2.11 Direction of the reaction force applied to a ski must be carefully matched against the static frictional characteristics of the grip wax during kick. This graph plots horizontal vs. vertical component of the ski reaction force during the kick phase and shows how good kick wax allows an advantageous orientation of the force vector. (Figure reproduced with permission Komi 1987.)

an angle such that the propulsive force component matches the maximum frictional force attainable for the conditions. An early kicking motion will compress the ski mid-section while the ski is moving and tend to decrease the glide unnecessarily. A late kick will compress the ski camber after the ski has momentarily stopped and will decrease the vertical force component which will in turn decrease the static frictional force from which propulsive force is generated.

Frictional characteristics of classical skis are in large part determined by the grip wax applied to the mid-section of the ski. Coefficients of friction for grip wax depend on wax constituents, temperature and ski stiffness and range from 0.2 to 0.4 when measured statically but are considerably smaller when a ski is in motion (less than 0.1). Maximum propulsive (horizontal) force of the kick from a ski is determined by the coefficient of static friction and the vertical force generated at the same time. Combining vertical force measurements made using instrumented skis and the coefficient of static friction, one can determine a theoretical maximum propulsive force for the diagonal stride kick of more than 0.4 times body weight. However, measured propulsive forces of the kick (0.1–0.25 times body weight) are considerably less than this theoretical maximum. This suggests that in typical diagonal striding, skiers are unable to use the frictional characteristics of grip wax to full advantage. Whether this shortcoming is a result of technique or mechanical characteristics of skis is unclear from the limited biomechanical testing currently available in the literature.

Diagonal stride in racing is primarily a technique for climbing. Uphill skiing reduces the glide phases of each stride compared to flat terrain and increases stride frequency. Temporal analysis of diagonal technique suggests that both the proportion of the stride as well as the absolute time where a ski is stationary are increased as slope increases. This is associated with an increased proportion of poling during a full stride. This adjustability of diagonal stride temporal proportions is part of what makes the technique well suited for climbing. A skier can maintain some propulsive force from skis and poles throughout most of an uphill diagonal stride. Unfortunately, we have little quantitative data describing the force and movement pattern changes associated with diagonal stride on varying terrain. We can only conjecture that optimizing technique on uphill terrain involves minimizing periods without propulsive force and this is best accomplished with diagonal stride rather than other classical ski techniques.

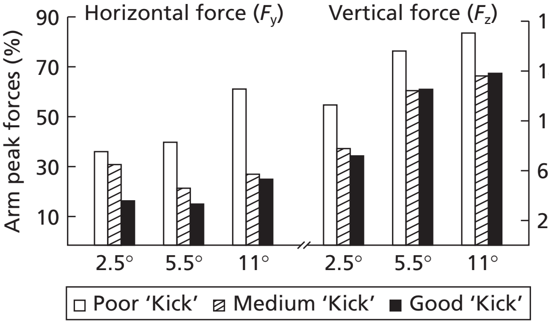

Fig. 2.12 Distribution of effort between arms and legs in the diagonal stride changes with slope and with kick wax characteristics. With moderate to good wax, about 15–30% of propulsive force comes from poling. (Figure reproduced with permission Komi 1987.)

As ski tracks vary from flat to steep uphill, the distribution of propulsive force across arms and legs probably changes to larger contributions delivered through poling. Because of the relationship of ski force perpendicular to the surface affecting the horizontal frictional force and grip of a ski during kick, it becomes more difficult to generate propulsive force from the ski as slope becomes steeper. Poling, in contrast, simply requires firm placement of the pole basket on the surface to generate propulsive force. This remains relatively constant from flat to steep uphills. Thus, the proportion of propulsive force from arms vs. from legs tends to increase as slope increases. This relationship is illustrated in Fig. 2.12 for three wax conditions. It is clear that slippery grip wax increases the reliance on arm propulsion during diagonal stride.

Arm and pole movement during diagonal stride is largely in the sagittal plane. Pole angulation at pole plant is slightly inclined forward of vertical (about 10–15°) with the amount of inclination slightly affected by skiing speed and slope. Poling forces are applied axially; that is, along the axis of the pole. Thus, pole inclination angle will affect the proportion of vertical and propulsive force at any moment. At 10° of pole inclination from vertical, the propulsive component of poling force would be less than 20% of the applied force, whereas at 45° the propulsive component would be greater than 70% of the applied poling force. It is clear that the effectiveness of poling force to propel a skier forward is greatly increased as the pole is inclined away from vertical (Fig. 2.3). Likewise, it is relatively ineffective to generate large poling force early during the poling phase as most of such force would go into a vertical component which does little to propel a skier.

Fortunately, arm structure can be used to advantage to minimize the metabolic costs for generating large poling forces. The poling phase movement pattern is mainly brought about by elbow extension coordinated with shoulder extension. In general, the elbow is probably strongest in mid-range. Thus, it would be advantageous if the arm were positioned so that the elbow is near mid-range extension when the poles are inclined substantially away from vertical. Elbow motion in poling often involves first flexion then extension of the joint. The initial phase from pole plant to nearly halfway through poling involves a relatively slow flexion of the elbow (Fig. 2.13). This flexion is probably associated with eccentric stretching of the triceps muscle crossing the elbow. Later in the poling phase, the elbow rapidly extends through mid-range to near full extension with the pole inclined substantially from vertical in a relatively effective angulation for propulsive force generation. This flexion followed by extension pattern allows the skier to apply some force to the pole early in the poling phase where the pole angle is not very effective for propulsive force without 'using up' any of the extension range of motion at the elbow. In addition, this pattern may preload the triceps, which may allow greater force generation and perhaps store some energy elastically to be returned moments later during elbow extension. This pattern of eccentric then concentric muscle activity is often called a stretch–shortening cycle and is thought to be a common part of locomotion patterns which results in improved metabolic economy. There is some indication that muscular stretch–shortening cycles may also have a role in the kick phase of diagonal stride as well as in other ski techniques. We observe a further example of this economizing method in the double poling technique discussed next.

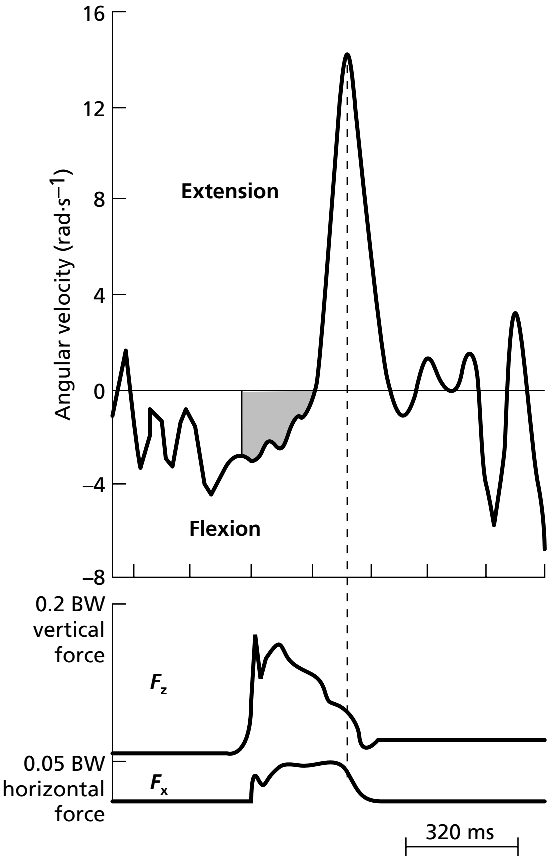

Fig. 2.13 Elbow angular velocity and poling force components during diagonal stride. Pole plant occurred where forces became non-zero on the graph. The shaded region of the angular velocity graph is where the elbow is being flexed while force is applied through the poles. This probably involves eccentric activity of the triceps muscle crossing the elbow and suggests that a stretch–shortening cycle is an important aspect of poling. (Figure reproduced with permission Komi & Norman 1987.)

Main points to remember about diagonal stride technique

- Propulsive force is generated from pole and ski reaction forces.
- Propulsive force from 'kicking' the ski is very brief and depends on vertical force during the kick, snow-wax conditions, and ski flex.
- Poling force propulsion increases as the pole angle moves away from vertical.

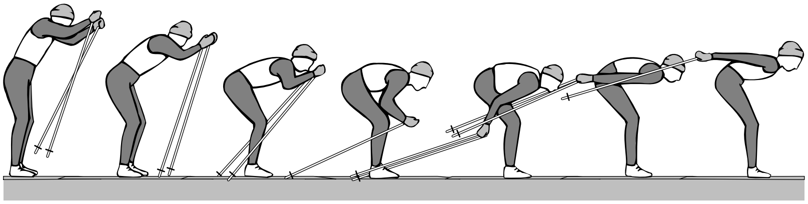

Fig. 2.14 Double poling technique involves a poling phase (positions 2–5) followed by a recovery phase of simply gliding. The length of the recovery phase is adjustable to meet the demands of high frequency sprinting or less intense double poling.

- Poling force contribution to propulsion increases as uphill slope increases, compared to kick propulsive force.
- Stretch–shortening cycle of leg and arm muscles can enhance both kick and poling forces during diagonal stride.

Double pole technique (Fig. 2.14)

In contrast to the asymmetrical arm and leg motions of the diagonal stride, the double poling technique involves both arms acting in unison and minimal leg involvement. Also unlike diagonal stride, considerable trunk flexion is involved in double poling and contributes to enhanced poling forces. All propulsive force generated in this technique is via arm and trunk activity delivered axially through each pole. Double poling is typically used under fast conditions or on horizontal track and on slight to moderate downhills where a glide phase would occur following poling. On slightly uphill terrain, double poling can be used by elite skiers with sufficient upper body power, but on steeper uphills where glide after poling would involve rapidly decreasing speed, double poling is infrequently used because of the high frequency and relatively large forces required. Several physiological tests of technique have compared double poling with diagonal stride, kick double pole and with several skating techniques. These suggest that double poling on flat and slightly uphill terrain may involve lower aerobic cost but higher lactate concentrations than other techniques.

What mechanical factors contribute to the effectiveness of double poling? Poling forces, ski reaction forces and drag forces (Fig. 2.5) are those that change with technique. Poling force effectiveness is perhaps the most complex of these relationships and we deal with it in some detail below. Ski reaction forces in double poling involve relatively little horizontal component of force; vertical ski forces are uniformly distributed across both skis and average less than half body weight because of vertical poling force during part of a cycle. Thus, the skis will be only moderately loaded during double poling and probably experience snow drag forces which are reduced from those of diagonal stride. Air drag force during double poling is also slightly reduced compared to diagonal stride because of the trunk flexion associated with poling. This reduces frontal area of the skier and probably drag coefficient; together these would reduce air drag acting against a double poling skier.

Poling force effectiveness depends on positioning of the trunk, shoulder, elbow, hand and pole (Fig. 2.3). Axial force is transmitted through each pole and has force components in the vertical and horizontal (propulsive) directions. As a pole is inclined away from vertical, the propulsive component increases for a given applied force. In double poling, pole inclination is affected by the complex interaction of trunk flexion, shoulder and elbow positioning. Pole positions with the greatest horizontal propulsive force components will be quite inclined forward of vertical. To get into such positioning requires trunk flexion combined with elbow extension. If these joint motions are coordinated, a skier's hands and pole handles can pass below knee level during poling with corresponding pole angles of more than 65° from vertical (Fig. 2.15). In diagonal stride during the latter part of poling, propulsive force is about 70% of poling force. In double poling, the more effective positioning of the poles allows as much as 90% of poling force to be propulsive.

In addition to larger pole inclination, arm positioning of shoulder and elbow may allow for generation of greater poling forces during later portions of poling phase where the pole is most effectively inclined. This advantage of double poling is because of trunk flexion which not only lowers the arm and pole but also allows the shoulder and elbow to remain in mid-range positions where greater joint torque resulting in greater poling force can be generated compared with

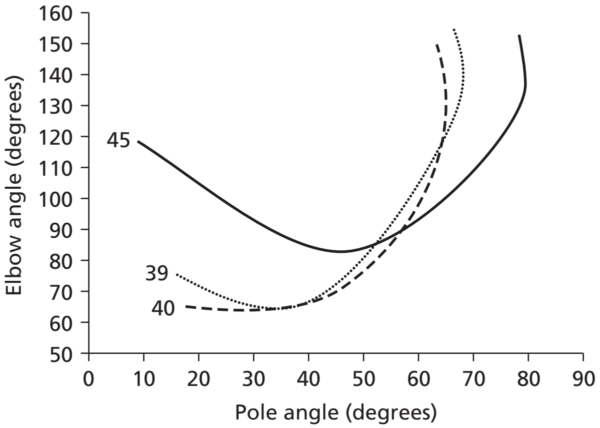

Fig. 2.15 Elbow angle vs. pole angle during the poling phase of double poling. Pole plant is at the left of each curve with the pole angled about 10–15° from vertical. Immediately following pole plant, elbow flexion (decreasing elbow angle) occurs for most skiers. This phase stretches the triceps muscles crossing the elbow prior to vigorous elbow extension later in poling phase. Graphs are for three skiers in the women's 30 km race of the Lillehammer Winter Olympics. (Figure reproduced with permission Smith *et al.* 1996.)

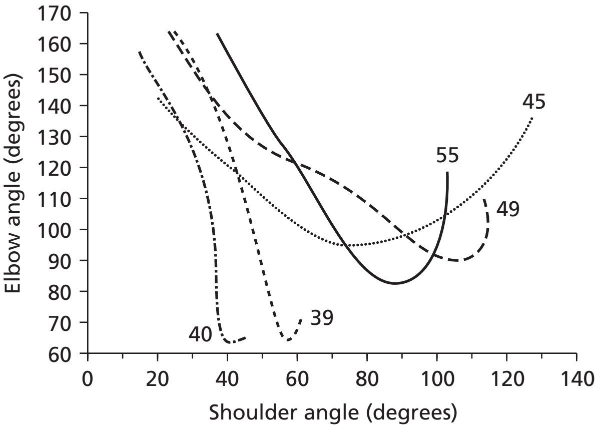

Fig. 2.16 Elbow angle vs. shoulder angle during poling phase of double poling. Pole plant is at the right of each curve. Differences in technique can be observed here. Most skiers plant the pole with the elbow extended in a position of 100° or more and then allow the elbow to flex through 20–30°. Other skiers choose to plant the poles with relatively flexed elbow and extended shoulder positions (e.g. skiers 39 and 40). While this allowed greater elbow range of motion throughout poling, it greatly diminished shoulder range. This pattern is probably disadvantageous although no poling force measurements comparing the patterns have been made to definitively determine effectiveness. Graphs are for skiers in the women's 30 km race of the Lillehammer Winter Olympics. (Figure reproduced with permission Smith *et al.* 1996.)

diagonal stride. In high speed double poling, at pole plant the shoulder is flexed slightly beyond mid-range and then extends throughout poling. The elbow, in contrast, is often somewhat extended at pole plant and initially flexes to 80 or 90° before extending late in poling (Fig. 2.16). This pattern is a more dramatic example of a muscle stretch–shortening cycle which was discussed above with respect to diagonal stride poling. Elbow flexion followed by extension is associated with triceps eccentric activity, which may enhance force development, followed by triceps concentric activity during elbow extension in a later poling phase. This combination allows for greatest force development when the pole is inclined at large angles and propulsive force generation can be maximized. Whether a similar stretch–shortening cycle occurs across the shoulder is uncertain. In some skiers, a small amount of shoulder flexion follows pole plant (e.g. skier number 49 in Fig. 2.16). Whether shoulder extensor musculature (largely latissimus dorsi in this case) is stretched after pole plant in double poling is unknown. Muscle activation patterns during double poling have not been measured; the kinematic characteristics of the elbow and shoulder described here suggest the possibility of muscle stretch–shortening but do not confirm such patterns. Our conjectures are based on observed movement patterns and anatomical principles but have not been directly measured.

Trunk motion during double poling is a central feature of the technique and may involve more than 45° of flexion during poling phase. Because of the large mass of the head and trunk and the considerable flexion that occurs, total body centre of mass oscillates vertically some 25–30 cm during a double poling cycle (Fig. 2.17). Coaching descriptions of double poling often highlight the importance of abdominal muscles to effective force generation. While both the abdominal and back extensor muscle groups are recognized as important contributors to dynamic trunk responses in skiing, it is *not* clear that the abdominal group is more important in double poling than it is in other techniques. In particular, poling forces are what propel a skier in double poling. The reaction forces acting on

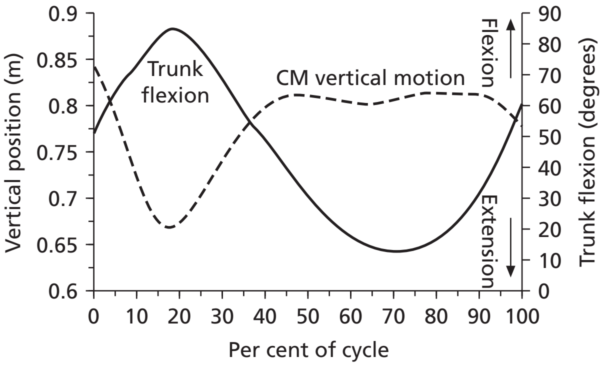

Fig. 2.17 Trunk angle and centre of mass vertical motion during a double poling cycle. A vertical oscillation of centre of mass occurs during poling phase of double poling. This is a result of the large trunk flexion preceding and during poling. (Figure reproduced with permission Smith *et al.* 1996.)

the poles and skis reflect the acceleration of the body's centre of mass. It is *upward* acceleration of the centre of mass that enhances pole reaction forces. Downward acceleration of a skier's body would serve to diminish the poling forces, thus forceful abdominal action to increase trunk acceleration downward would be counterproductive for poling force generation. Instead, trunk flexion during poling is probably controlled largely through the back extensor musculature which allows gravity to flex the trunk. The trunk's weight contributes to poling forces as it is partially supported through the arms and poles, but probably the most important role that trunk flexion plays in double poling is to put the arms into an advantageous position for generating propulsive force during poling.

Main points to remember about double poling technique

- Propulsive force derives completely from arm–trunk activity in double poling.
- Poling effectiveness depends on positions of trunk, shoulder, elbow, hand and ski pole.
- The propulsive component of force increases as pole angle moves away from vertical.
- Trunk flexion during double poling helps put the poles into a more effective, more inclined position late in poling phase.
- Stretch–shortening cycle may enhance elbow extension muscle force and contribute to greater poling force.

Kick double pole technique (Fig. 2.18)

The double poling technique is very effective under fast conditions where a glide phase between poling actions does not involve substantial slowing. When good glide is not available because of snow conditions or slight uphill, an additional propulsive kick phase can be inserted between poling actions to maintain momentum. The kick phase of this technique is similar to that of diagonal stride. It depends on a momentarily stationary ski gripping the surface and a careful balance of vertical, propulsive and frictional forces. Right and left leg kicks are often alternatively used in straight tracks while the technique is easily adapted to skiing curves with repeated kicks on one side.

Skiing speed in all ski techniques is determined by basic cycle characteristics of stride length and stride frequency (number of cycles per second). Theoretically, speed can be increased by increasing stride length or frequency. However, in practice skiers control speed at any moment largely by adjusting the frequency of striding while changing stride length relatively little. This is clearly seen in Fig. 2.19 where kick double pole technique on flat terrain was observed to increase frequency by about 20% as skier speed increased by 10% and while stride length decreased by about 4%. Other ski techniques also control speed in a similar manner; however, it should be noted that beyond normal race speeds either slower or at maximum, more dramatic decreases of stride length are observed.

Timing of a cycle in double poling is largely determined by the extent of glide following poling. This

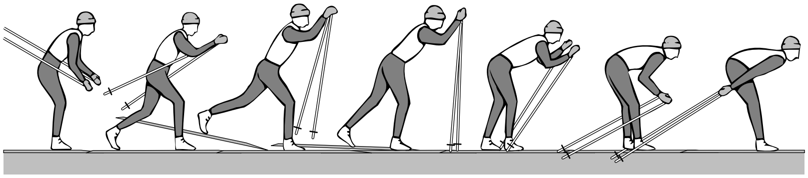

Fig. 2.18 Double pole with kick technique involves a brief kick (positions 1–3) and a poling phase (positions 4–7). Not shown is a recovery phase of gliding on the skis until the next stride begins.

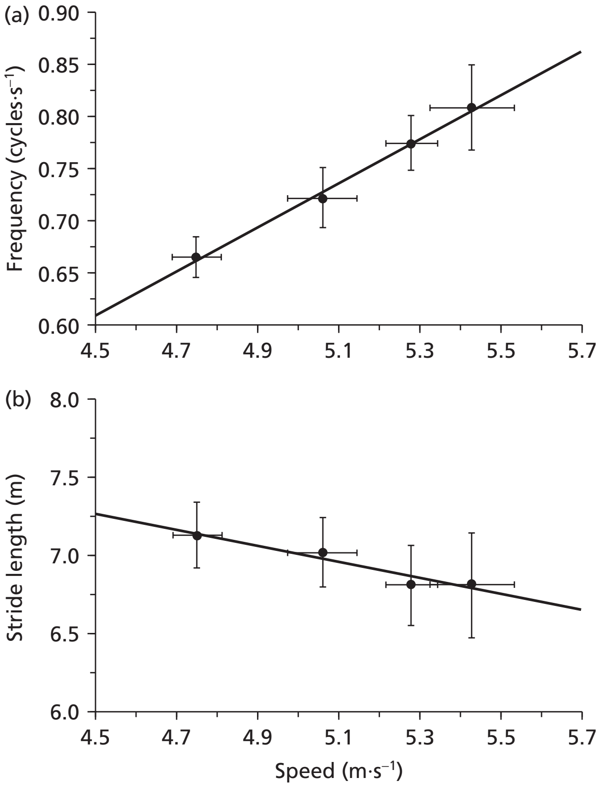

Fig. 2.19 (a) Stride frequency and (b) stride length vs. skiing speed for double poling with kick. Skiers control speed largely through adjustment of stride frequency while stride length changes much less. (Data from Smith 1985.)

can be very brief when a skier is sprinting or can be relatively long when on downhill terrain. In contrast, when a kick is included with double poling, stride times cannot be as short as high-frequency double poling. A skier must judge the relative advantages of additional propulsive force during a longer stride vs. high stride frequency when deciding between double poling with or without a kick. Optimization of technique depends on snow conditions, skiing speed, wax grip and glide characteristics and a skier's physiological attributes at any given moment. Unfortunately, much of the mechanical data about the force–time characteristics of double poling with or without a kick are simply unknown at present. This shortcoming makes discussion of ski technique optimization more conjecture based on intuition and physical principles than on kinetic data.

Main points to remember about kick double pole technique

- Adding a kicking motion to double poling increases the total propulsive force component.
- Kick double pole stride frequency cannot match the high tempo capability of straight double poling.
- Speed control in kick double poling and in other ski techniques is primarily by adjustment of stride frequency while stride length is relatively unchanged through typical skiing speeds.

Ski-skating techniques

Skating has been part of cross country skiing for decades as part of single step turns. Occasionally, when unusual surface conditions allowed it, more extended periods of skating were used on natural snow or ice surfaces. Skating is largely about glide on a ski and requires smooth well-packed snow which has only become consistently available since mechanical grooming was more widely introduced in the late 1970s. It is therefore not surprising that skating for extended periods is a relatively recent phenomenon and that the techniques for most effective and economical performance are still evolving. Skating became an official part of international ski-racing with the introduction of 'freestyle' races in the 1985–86 season. The early skating techniques and the subtly different variations that have evolved since then all rely on a common mechanism for generating propulsive force from a ski: if a ski is placed on edge, a skier pushing through the ski to the snow generates reaction force components in both vertical and horizontal directions acting on the ski. When the ski is angled with respect to the forward direction, this horizontal reaction force can be propulsive.

Ski reaction forces in the skating techniques are orientated approximately perpendicular to the ski surface. Because skating skis are prepared with glide wax and are without the grip waxes required for classical skiing, there is no means of using static friction to generate propulsive force. In a manner similar to speed skating, the ski is set down at an angle to the forward direction and while gliding it is placed on edge. The edged platform of the ski resists forces perpendicular to it as these simply compress the snow under the ski. Forces in other directions cannot be generated as the frictional

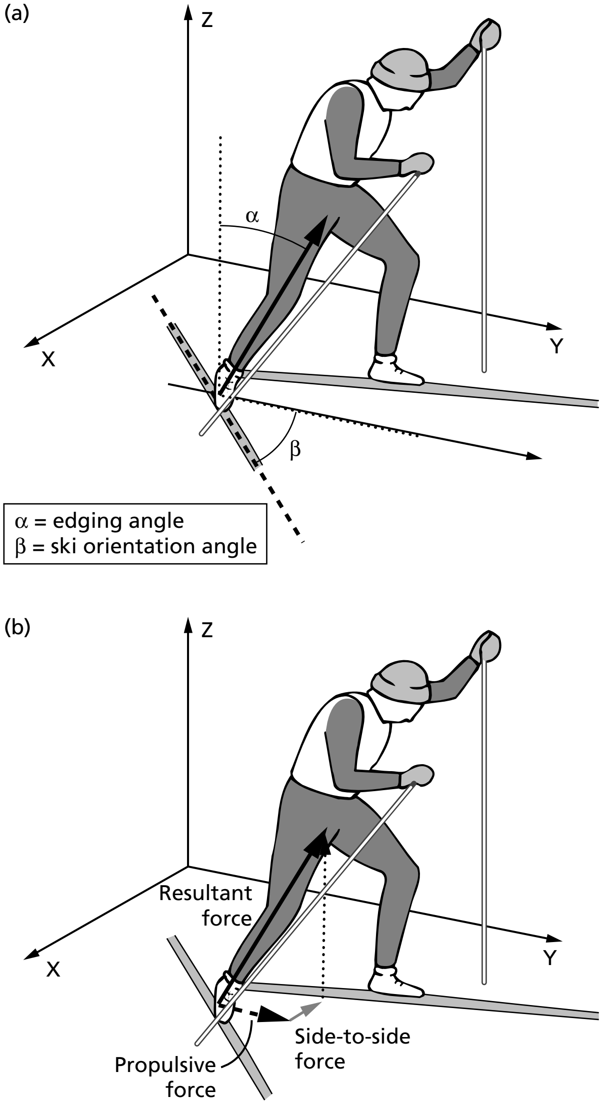

Fig. 2.20 Ski reaction force in skating is aimed approximately perpendicular to the ski surface. To determine the components of the resultant force, ski edging angle (α) and ski orientation angle (β) must be measured. Using the resultant force and sine functions of these angles, propulsive force can be calculated.

forces are insubstantial. Figure 2.20 illustrates the resultant ski reaction force perpendicular to the ski surface; components can be determined if the ski positioning with respect to the snow surface (edging angle) and with respect to the forward direction are known. With resultant ski force (F_{ski}) normal to the ski surface, each of these angles affects the propulsive component as the sine of the angle. Thus, propulsive force component from a skating ski can be calculated from:

$$F_{propulsive} = F_{ski} \sin \alpha \sin \beta,$$

where α is the edging angle of ski surface with respect to snow surface (0° being flat) and β is the orientation angle (0° being straight ahead). From this equation it is obvious that propulsive force increases (for a given resultant ski force) as either the orientation angle or the edging angle increases.

A common observation in skating is the relationship of ski orientation angle to skiing speed. On flat and fast terrain, the skis are angled away from the forward direction a relatively small angle while under slower conditions and on uphill terrain the ski angles increase substantially. For example, from several Olympic studies we know that on flat terrain ski angles were about 6–8° (men) and 10–12° (women) while skiers on uphill terrain skated with much greater angle of skis to the forward direction (about 28–30°). Mechanically, this response would be expected based on the relationship of ski angle to propulsive force component. On the flat, only air and snow drag forces resist a skier's motion, requiring relatively modest propulsive forces to maintain skiing speed. On uphill terrain, gravity is an additional force against which a skier is working. This requires greater propulsive forces to maintain uphill skiing speed. These greater propulsive forces can be generated by increasing the resultant ski reaction forces, by increasing the ski angle with respect to forward direction (β in the equation above) or by increasing the ski edging angle on the snow surface (α). While no force comparison of flat to uphill skiing is available, ski forces have been measured on grades of 9 and 14%. For these moderate and steep uphills, average forces were similar while ski orientation angles changed with grade. Based on this evidence, it is likely that skiers maintain similar skating force magnitudes on different terrain but generate greater propulsive force mainly through adjustment of ski orientation and edging angles.

While ski edging angle may affect snow drag force (see Fig. 2.29 and accompanying discussion), ski orientation angle interacts with other kinematic characteristics of a skating stroke. As ski angles increase away from the forward direction, a skier's lateral displacement during the stroke increases and displacement in the forward direction may decrease. The

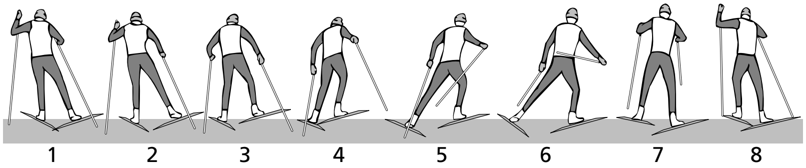

Fig. 2.21 V1 skating technique involves a double poling motion synchronized with a skating stroke on one side (referred to as the strong side) while the arms are in recovery swinging forward during the skating stroke on the other side (weak side). The skier in the figure is poling during the first half of the cycle shown (positions 1–4) while skating on the left (strong) side. Last half of the cycle involves skating on the right (weak) side.

changing orientation angle of a ski from flat to uphill terrain also results in a modification to the effective slope up which the ski is gliding. By angling the ski laterally, a skier can increase the glide distance during a skating stroke and the glide time before the ski speed decreases substantially. Thus, increased orientation angle of the ski can accomplish two things: the propulsive force component can be increased and uphill ski glide can be enhanced. These come at the expense of increased lateral motion which may be constrained by topology of the surroundings. As displacement in the forward direction during a cycle decreases with increased ski angle, a skier must increase the skating stroke rate to maintain speed but this would come at the expense of glide on each ski. At some point, stroke rate limitations combined with race course width limits restrict a skier's ability to use greater ski angles to increase propulsive force without exceeding physiological optima. These and other factors influence a skier's choice of skating technique. The main skating variations used in racing involve differences in poling timing and ski placement. These are discussed (below) within each of the primary skating techniques currently used.

[Note: the naming of skating techniques is not well standardized in English. We will use the terminology V1 and Open Field skate to refer to skating patterns where one double poling action is used per full cycle involving two skating strokes. V1 and Open Field differ in timing of poling with respect to the skating stroke. In contrast, V2 is a pattern with two poling actions per cycle; one double poling action with each skating stroke.]

V1 skating technique

Just as diagonal stride is used under conditions where there are relatively large resistive forces (uphill, headwind, or very slow snow), V1 skating technique is used similarly. Rather like a low gear, V1 skating involves slightly higher frequency than does V2 or Open Field when used at similar speeds. As can be seen in Fig. 2.21, an asymmetrical application of poling is involved with both poles operating nearly together along with one side's skating stroke but not the other skate. Pole positioning is also different on each side. These side-to-side differences have been named in a variety of ways by coaches. A common phrasing is to call the side for which skating and poling are together the 'strong' side while the side where skating occurs without poling is the 'weak' side. In this phrasing, one would refer to the strong side pole or the weak side ski, for example. These terms are not to imply that the poling or skating forces on the weak side are necessarily less than the strong side but simply designate a synchronization of propulsion from poling and skating. In Fig. 2.21 the skier is poling while skating on the left side, so the left side is the 'strong' side and right side is the 'weak' side. In the figure, typical pole positioning can be observed. The strong side pole is planted in a nearly vertical position and poling continues with the pole orientated close to the forward direction. The weak side pole is inclined further from vertical at pole plant and is orientated in the direction of the strong side ski.

As a technique well suited for uphill skating, the ski positions in the V1 can be adjusted from rather narrow to quite a wide 'V' between skis as required to suit hill steepness. Wide 'V' placement positions the skis somewhat across an uphill and allows them to glide further than if placed straight uphill. Each ski must be edged during its skating stroke to generate propulsive force components and this is accomplished as a skier smoothly pushes from one ski onto the other with a complete weight shift. The asymmetrical pole positionings are partly a result of the typically wide 'V' ski

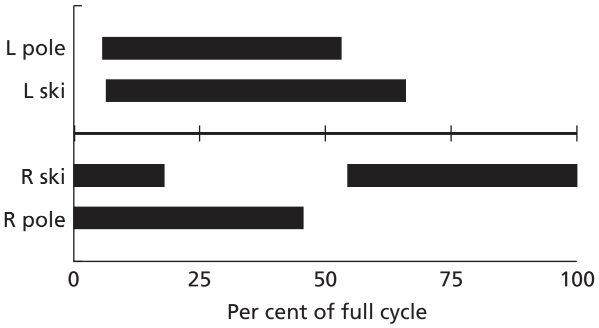

Fig. 2.22 V1 skate phase diagram. The bars represent points in a full cycle when poles or skis are in contact with the snow. The pattern shows poling along with left side skating in the first half of the cycle. Skating on the right ski continues through the last half and slight overlaps with the next cycle.

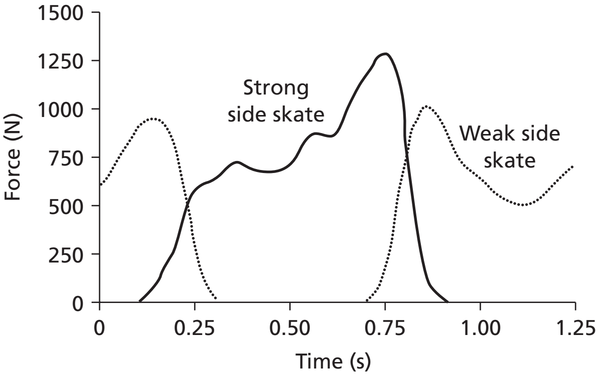

Fig. 2.23 V1 skate reaction forces. The graph begins with time = 0 at initial pole plant of the weak side pole. Strong side skating begins approximately synchronized with the strong side pole plant. Reaction forces in skating are relatively smooth and reach magnitudes of about two body weights.

positions on uphills. The weak side pole must be outside of the weak side ski and not interfere with its glide. As the skier is stepping forward from that ski, this necessitates a more lateral positioning of the pole plant. In addition, the orientation of the weak side pole toward the strong side ski (rather than forward) serves to enhance glide in that direction and to facilitate weight transfer from the weak side to the strong side ski. Timing of the V1 skate nearly synchronizes poling with stepping onto the strong side ski. Poling ends as the skier skates from the strong side and steps onto the weak side ski. These temporal relationships are illustrated in the phase plot of Fig. 2.22. As with many ski techniques, phase proportions of the V1 skate are adjusted as terrain and snow conditions require.

Skating forces applied to the skis are primarily perpendicular to the ski surface. In V1 skating, these resultant forces are modest when compared to running or jumping. Resultant skating forces reach peak values of about 1.5–2 times body weight. Force patterns on the weak side ski are similar to the double peaked ground reaction forces of walking and similar to those observed in other skating strokes. On the strong side, skiers may often step onto the ski more smoothly because of concurrent poling. For many skiers, the smoothly increasing force to a peak is observed. This pattern is probably advantageous in reducing snow drag force and allows the ski to plane more smoothly over snow, enhancing glide.

A variation on the V1 technique often used in uphill sprinting involves a brief jump from one ski to the other. This serves to enhance forward motion of the skier up the hill but may also increase the ski reaction forces as the skier lands from the forward jump. Such increased forces as the ski contacts the snow may increase snow drag force compared to a smoother force application of ski on snow (Fig. 2.23).

Poling forces in V1 skating are about half of a skier's body weight, at maximum. When the resultant forces from skis and poles are resolved into their component directions, the relative effectiveness of these propulsive sources can be analysed. Ski-skating propulsive force depends on the ski's orientation with respect to forward and on its edging angle. Because of the multiplication of the sine function of each of these angles (Fig. 2.20), propulsive force is a relatively small fraction of the resultant skating force. In contrast, propulsive poling force depends mainly on the angle of pole inclination. While not as effectively angled as is seen in the classical double pole technique, V1 poling does develop substantial propulsive force. When analysed over a full V1 skating cycle, average propulsive force from each pole is about 10% of body weight, while each ski develops about 6% of body weight (Smith 1989). These proportions of propulsive force suggest that V1 skating on uphill terrain is driven in large part by poling forces from arm and trunk musculature. On flat terrain, it is likely that somewhat less reliance on poling force may typically be used in skating. Never-

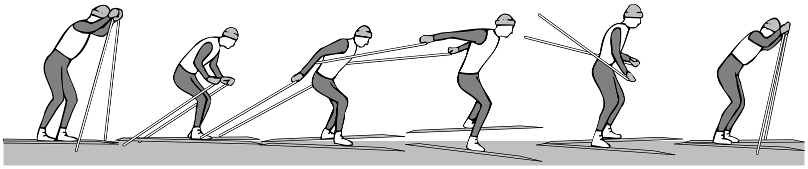

Fig. 2.24 Open Field skating involves a double poling action synchronized with the end of a skating stroke on one side (strong side) while the arms swing forward in recovery during the second skating stroke (weak side). Considerable glide occurs with both skating strokes which increases overall cycle length and decreases cycle frequency for the Open Field technique.

theless, it is clear that high level skiers require the ability to generate substantial poling force.

While V1 skating involves using both poles almost synchronously, the movement patterns during poling are somewhat different than observed with classic double poling. Trunk flexion during V1 poling is less than 25° or about half that observed in double poling. Body centre of mass vertical motion, about 15 cm, is similarly much less than in double poling. Unlike other skating techniques, the trunk flexion and centre of mass drop is in part done prior to poling. This timing results in the lowest centre of mass position near the end of poling and near the end of strong side skate. The upward reaction forces associated with this downward then upward motion of the trunk serve to enhance poling and skating forces when poles and skis are most effectively orientated for propulsive force. In contrast, the V2 and Open Field skating techniques described below use other timing strategies to enhance propulsive force.

Main points to remember about V1 skate technique

- V1 skating is asymmetrical with poling accompanying skating on one side but not the other side.
- Ski placements in V1 skating often involve a relatively wide angle of each ski with respect to forward. This forces pole position to be asymmetrical at pole plant.
- Propulsive forces from a skating stroke depend on ski angle with respect to forward and ski angle with respect to the snow surface. Ski propulsive force is relatively small until substantial ski edging occurs.
- Propulsive forces from poling depend on pole orientation and on pole inclination angles. Poling effectiveness increases as the pole moves away from vertical.
- In uphill skating, poling contributes more than half of the propulsive force.

Open Field skating technique

At first glance, the Open Field skate may be mistaken for the V1 technique described above. It involves poling along with one side's skating stroke but not the other side, as does V1, but, in contrast, Open Field skating is used primarily under fast conditions and is rarely used on slopes more than modestly uphill. The difference is in glide under these conditions.

Figure 2.24 shows the movement pattern involved in Open Field skating. Double poling in the illustration is occurring at the end of left ski glide. This association would make left the skier's strong side in this case. Poling and the strong side skating stroke end as the skier steps onto the other ski (weak side). The combined poling and skating impulse briefly accelerates the skier onto the weak side ski. Under fast conditions considerable glide is obtained on this ski before skating back onto the strong side ski. Subsequent poling occurs after additional gliding on the strong side ski. Timing of these poling and skating phases is subtly different than in V1. Under fast conditions an Open Field skating cycle may be 1.5 s or more in duration. In contrast, V1 is usually shorter at 1.2–1.3 s. The additional time is spent gliding on either ski. In particular, considerable glide is obtained on the strong side ski before pole plant, poling phase and a propulsive skating stroke. In V1, pole plant and strong side skating occur almost synchronously (Fig. 2.25).

With more time, the double poling motion of Open Field skating can involve a larger range of trunk flexion and greater vertical centre of mass motion. This increases pole inclination to a more effective positioning for generating propulsive force. On flatter terrain typical of the Open Field technique, ski placements are much closer to the forward direction (less than 10°). This allows both poles to be orientated

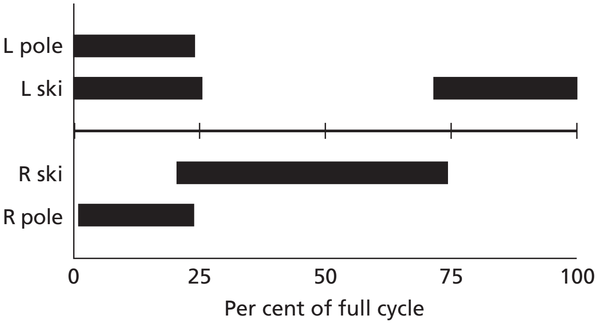

Fig. 2.25 Open Field skate phase diagram. The bars represent points in a full cycle when poles or skis are in contact with the snow. The pattern shows poling along with left side skating in the first quarter of the cycle. Skating on the right ski continues through the middle half. Skating on the strong side (left) begins well before pole plant. Note this timing difference compared with V1 skating. Considerable glide occurs on the strong side ski prior to poling.

nearly forward—also increasing the effectiveness of Open Field poling over that which is possible with the V1 skate. Unfortunately, systematic measurements of pole and ski forces in the Open Field (and V2) techniques have not been carried out. Thus, the proportions of propulsive force of poling and skating are unknown.

Main points to remember about Open Field skating technique

- Open Field skating is typically used on relatively flat or gently rolling terrain and involves narrowly angled skis during the skating strokes.
- Open Field skating has subtly different timing of poling and skating phases compared to V1.
- Poling occurs after an initial glide phase on the strong side ski. Stepping onto the weak side ski is synchronized with the end of poling and the end of strong side skating.

V2 skating technique

Unlike V1 or Open Field skating, the V2 technique involves symmetric poling–skating movement patterns on each side. Used primarily under fast conditions on the flat or to maintain momentum over rolling terrain, V2 has become widely used in recent years of racing. Elite skiers may occasionally use V2 on steeper uphills but this requires considerable upper body power. Timing of the double poling action is similar to that of the Open Field skate with respect to the strong side skate stroke. In V2, poling occurs near the latter part of each skate stroke as the skier is about to step from the skating ski to gliding on the other. Figure 2.26 illustrates this pattern for half of a V2 cycle. The second half of the cycle repeats with a similar poling pattern while skating on the other side. A visual comparison of the poling phases of V2 and Open Field skating (Figs 2.26 and 2.24) confirms the similarity of the two techniques.

While poling–skating patterns are similar in the two techniques, timing is dramatically different. Overall cycle times for V2 range from 1.5 to 2 s. Thus, each of the poling actions must be completed in less than 1 s—much less time than is available with the other skating techniques. This requires considerable acceleration of the arms with each poling motion. As V2 frequency increases (e.g. when sprinting), range of motion at the shoulder and elbow in late poling may be reduced to decrease poling time and quicken recovery to the next poling action. The rapid sequencing of pole plant, eccentric then concentric muscle activity probably facilitates enhanced force generation of the stretch–shortening cycle. An additional consequence of the brief time available in poling is the modest trunk flexion that occurs. There simply is no time to move the trunk down and then recover in position and in time for the next pole plant (Fig. 2.27).

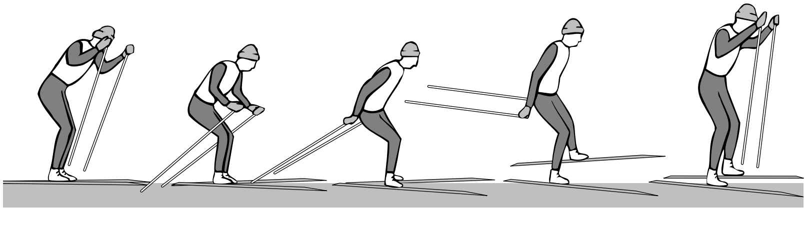

Fig. 2.26 V2 skating involves a double poling action with each skating stroke. This requires rapid return of the arms to a forward position ready for the next pole plant. Overall frequency of V2 is low and stride length relatively large compared to V1 and Open Field skating. This diagram shows only the first half of a V2 cycle.

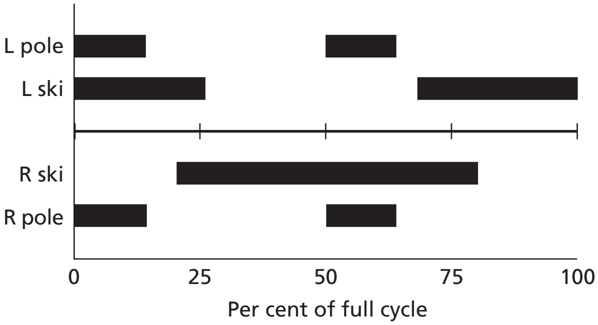

Fig. 2.27 V2 skate phase diagram. The bars represent points in a full cycle when poles or skis are in contact with the snow. The pattern shows poling along with left side skating in the first quarter of the cycle. Poling with right side skating occur in the last half of the cycle. Note the extended glide on each ski prior to poling. (Data for V2 phases of this diagram from Bilodeau *et al*. 1992.)

Forces in V2 skating follow the pattern shown in Fig. 2.28. The two peaks in each skating stroke correspond with initial ski set down and with a vigorous propulsive thrust at the end of the stroke which helps transfer a skier's weight to the other ski. As ski angles in V2 skating are generally quite small (skis aligned close to the forward direction), the propulsive forces that can be generated during each skate stroke cannot be very large. However, when combined with strong double poling, sufficient propulsive force can be generated to maintain speed on flat terrain and even on steeper uphills for powerful upper body skiers. Unfortunately, no systematic study of V2 skating forces has been undertaken currently and we know relatively little about how propulsion is distributed between poling and skating forces.

Main points to remember about V2 skating technique

- In V2, a double poling action accompanies a skating stroke on each side, so it is a symmetrical technique.
- Overall timing for a complete V2 cycle is longer than for other skating techniques, but the time for each double poling action is much shorter. This demands considerable acceleration of the arms swinging forward in recovery for the next poling phase.
- With the short time interval of poling, the elbow flexion followed by extension seen in double poling may facilitate stretch–shortening cycle enhancement of force.

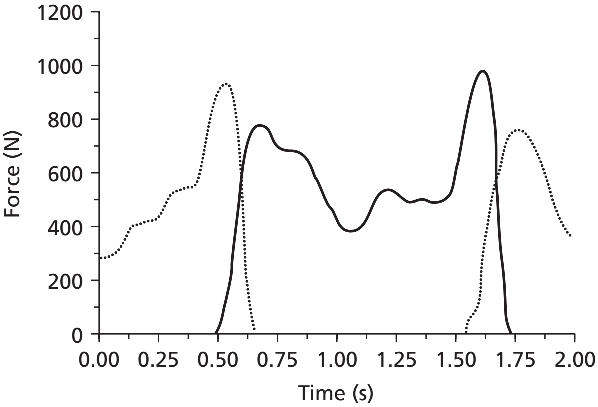

Fig. 2.28 V2 skate reaction forces. The graph begins with time = 0 at initial pole plant. The second poling action begins at the mid-point of the cycle.

- Ski angles in V2 are quite narrow, hence skating stroke propulsive force is relatively small. Pole forces probably provide most of the overall propulsive force in V2 skating.

Other skating techniques

While V1, V2 and Open Field techniques are the primary choices of skating skiers, several alternatives are used under certain conditions. Variations of ski technique are in some ways analogous to gearing of a bicycle or car; low gears are used up steep hills, high gears on downhills. V1 skating is generally of higher frequency (like a lower gear) than either Open Field or V2 techniques, but occasionally very steep slopes are encountered which require an even lower gear. Diagonal skate, sometimes called flying herringbone, combines contralateral arm and leg actions. Single poling is synchronized with a skating stroke of the opposite side and the direction of poling is orientated nearly parallel with the skating ski. This enhances glide during each skating stroke and allows progression up very steep slopes.

'High gear' skating must sometimes exceed speeds at which V2 is effective. As speed increases, the time available for poling decreases because the stationary planted pole basket passes out of reach behind a skier in a time period too short for generating force but free skating without poling remains possible under high-speed conditions. Skating is an unusual mode of locomotion which does not require the ski (or skate) to be stationary. Despite gliding forward, when placed on edge the ski can be used as a platform from which to skate. Provided a ski is orientated at an angle to the forward direction, skating from the edged ski will create propulsive force even at high speed. Free skating in this manner is used under very fast conditions and generally involves ski placements at somewhat wider angles than would be seen for V2 skating over the same terrain.

Finally, marathon skate technique is sometimes used when a classical track is available along with a skating lane on flat terrain. With one ski gliding straight ahead in set tracks, the other ski is placed at an angle to it out of the tracks and with a skating stroke used to propel the skier. Double poling is combined with the skating stroke into a propulsive phase followed by an extended glide on the track ski. Marathon skating can be relatively fast and is a relaxing alternative to other skating strokes. It was the first skating technique used for extended periods of skiing during the transition period of skating technique development of the early 1980s.

What makes skating fast?

Within several years of exploration of skating, the marathon skate, then V1, V2 and Open Field skating became distinct movement patterns. As early explorers of skating won more and more races in the 1980s, it was clear that skating techniques are usually faster than classical techniques. Comparisons of race times over comparable distances, terrain and conditions suggest that skating can be as much as 20–25% faster than classical skiing. What factors contribute to this advantage?

Ski motion during skating differs from ski motion during diagonal stride or kick double pole in two respects: skating skis glide throughout a stroke while kicking; a classical ski requires it to be momentarily stopped. Secondly, skating requires a ski to be placed on edge forcing the ski to bite into the snow while classical skis run flat on the surface. These differences provide both advantages and disadvantages for skiing speed.

By performance, it is clear that continuous gliding during skating provides greater advantage than is lost because of increased drag force due to ski edging. Propulsive force in skating is generated by reaction forces perpendicular to a ski's surface. Being perpendicular to the ski surface, reaction forces during skating have no component in the direction of the ski and do not slow it down. This allows displacement of the ski during propulsion unlike the stationary requirements of kicking a classical ski. Coaching suggestions to skaters often include the comment 'push through the heel' to minimize any tendency to step forward off of the ski rather than laterally. Such inappropriate stepping forward introduces a reaction force which slows a ski's glide and interferes with skating performance. Optimal skating technique keeps reaction forces perpendicular to the ski which allows glide to continue during a skating stroke.

Ski edging has long been thought to affect glide characteristics of both alpine and Nordic skis. Ski edging angle is a measure of a ski's flatness to the snow surface. It is thought to influence glide by affecting ski penetration into surface snow layers which may increase snow drag force while providing a firm platform from which skating forces are generated. Conventional wisdom from ski coaches suggests that a 'flat ski' will glide faster than an edged ski. In skating, glide directly affects cycle length. As faster skiers tend to ski with greater cycle lengths it is a common connection to relate ski edging to glide and to performance. While it is reasonable to expect snow drag forces to be greater on an edged ski than on one that is flat (because of deeper penetration and increased plowing), this has not been demonstrated and the magnitude of the increased drag is unknown. The typical description of fast skating techniques like the V2 and the Open Field includes a long glide phase on each ski prior to pushing off with a vigorous knee extension. The implication of some coaching suggestions is that a relatively static flat ski position be maintained during the early parts of each skating stroke where the ski is mainly gliding.

However, this static flat ski emphasis is not typical of elite skiers. Figure 2.29 illustrates mean ski-edging angles during fast skating on flat terrain during the men's 50 km race of the 1992 Olympics. None of the 17 elite skiers analysed in that study exhibited a ski-edging phase where a flat ski was statically maintained. Most skiers set the ski down on the snow initially with it being flat to the surface and all moved away from the initial positioning immediately. Static posturing to enhance ski glide has not been observed

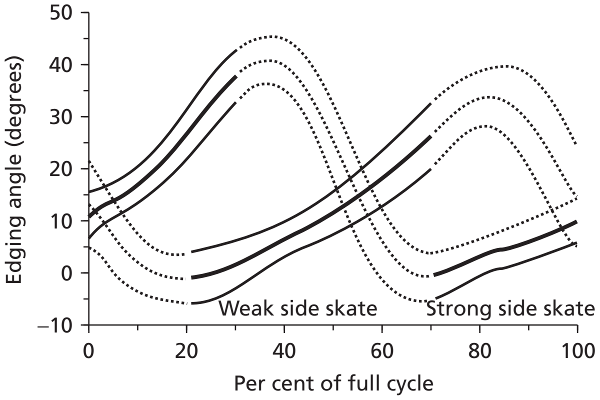

Fig. 2.29 Ski edging angle during Open Field skating. Heavy solid lines are mean edging angles during each skating stroke when the ski was in contact with the snow. Curves above and below the mean values are ± 1 SD based on the 17 skiers of this study from the men's 50 km race at the 1992 Winter Olympic Games, Albertville, France. Note the skiers set down the ski in a nearly flat position (0°) and then smoothly increased edging angle until the end of the skate stroke. Skiers did not maintain a flat ski to enhance glide but smoothly changed edging angle. (Reproduced with permission Smith & Heagy 1994.)

for elite skiers and it is likely to be a disadvantageous skating technique at race pace. This observation must not be misunderstood to mean that ski edging and a flat ski are unimportant characteristics for ski glide. Note in Fig. 2.29 that despite smoothly increasing edging angles on the strong side skate over the last 30% of the cycle, the ski is only 10° from flat. This modest amount of edging may have little effect on ski glide while allowing a skier to dynamically stroke from side to side. It is only later in each skating stroke, when ski reaction forces are largest, that the skis are substantially edged. Some skiers are observed to set the ski down on the lateral edge (negative ski angle), rotate through flat and onto the medial ski edge during the glide phases on each side. This technique may be advantageous on flat fast terrain as it may prolong the time where the ski is within a few degrees of flat while promoting a continuous dynamic movement toward the next skating stroke.

While ski glide is essential in skating, it is also a crucial component of fast classical skiing. The following sections will address equipment and technique characteristics which affect glide and overall skiing performance.

Main points to remember about skating fast

- Skating is as much as 25% faster than classical skiing under some conditions but the difference varies according to the terrain, e.g. in steep uphills both techniques may be as fast.
- Force applied to the ski by the foot should be perpendicular to the ski surface. Pushing backward will only serve to decrease the ski's glide speed and will not increase propulsive force applied to the skier.
- Ski edging is an essential aspect of generating propulsive force in skating. However, edging also affects the snow drag force applied against a ski's motion. A flat ski will glide with less deceleration than an edged ski.
- Despite an advantage of better glide with a flat ski, an exaggerated emphasis on flatness during glide may introduce a disadvantageous delay to a skating stroke. Elite skiers set the ski down flat but immediately begin rolling the ski on edge as the skating stroke progresses.

Drag forces, equipment and performance

Drag forces

Newton's laws describe the effects of forces on motion of an object. The vector sum of all forces acting on a skier determines motion changes. As shown in Fig. 2.5, reaction forces at the poles and skis are important components affecting skier motion. These reaction forces are affected by skier technique and strength and have the characteristic patterns illustrated above. However, the resistive forces caused by air and snow also have a substantial influence on a skier's performance capabilities. These can dramatically affect skiing speed and influence technique execution and choice. While equipment in skiing is relatively simple, its interaction with snow and air directly affect performance. Aspects of aerodynamics and snow friction will be introduced in the following sections along with discussion of equipment and technique choices to minimize drag forces acting on a skier.

Aerodynamic drag

'Air resistance' can be thought of in terms of force acting on a body because of the flow characteristics of fluids through which the body is moving. The branch of physics called fluid mechanics includes two components that contribute to development of drag force acting against a skier's motion. ('Fluid' in this context means a medium, like air, which can flow around an object.) The two components depend on an object's surface characteristics and on its shape and size and they are often referred to as skin drag and profile drag. Skin drag is a force acting against the direction of motion which derives from local characteristics of fluid flow at the surface level of an object. In some sporting situations (e.g. swimming) skin drag is of consequence, but in skiing it is of relatively small magnitude compared to profile drag and snow drag forces and is not discussed further here.

Profile drag force is generated as a skier moves through air and depends on a skier's overall shape and size. With motion, air flows around the body, skis and poles and exerts varying pressure patterns on the front, back and sides of a skier. Steamlining of the body and equipment can smooth the air flow patterns and minimize pressure differences from front to back of a skier. It is air pressure difference applied across an area of the body which creates profile drag force (and explains why it is also referred to as pressure drag). If a skier can reduce pressure differences and can reduce the area upon which the pressure difference acts, profile drag force can be reduced.

Body shape of a skier is not easily adjusted within the constraints of techniques for propulsion. Hence, relatively little is usually done to minimize air drag under normal conditions of flat and uphill skiing. However, on downhills where speed is greater and where gravity provides propulsive force, or when head winds are encountered, ski technique is often modified to minimize air drag forces. In these circumstances, the relative velocity of air past a skier can be considerably greater than the 5 or 6 m·s^{-1} average speeds in racing. Because profile drag force increases as the mathematical square of relative velocity, modest increases of air flow past a skier can substantially increase drag force. Figure 2.30 illustrates typical profile drag forces as a function of speed for upright and tucked body positions. Notice how dramatically profile drag force increases with speed. At 5 m·s^{-1} about 10 N of profile drag force act against a skier; doubling speed to 10 m·s^{-1} quadruples profile drag force to 40 N. Changing body position from upright to tucked (e.g. Figs 2.1 and 2.4) is a common strategy on downhill terrain which reduces air drag by more than half. This advantage results both from streamlining of air flow around the body (reducing pressure differences) and from reducing frontal area compared to upright.

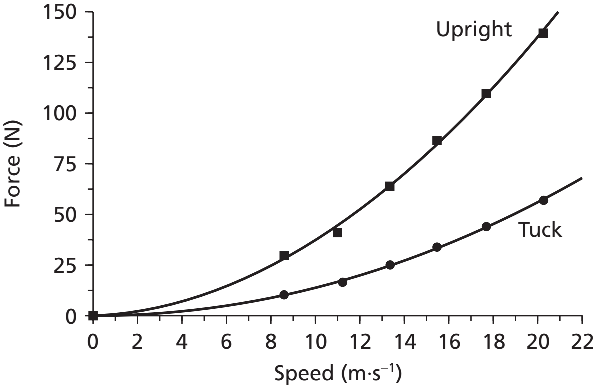

Fig. 2.30 Air drag force vs. speed for upright and tucked positions. (Data from Svensson 1994.)

Skiers on flat terrain encountering head winds have more difficulty in dealing with air drag force. A modest head wind of about 2 m·s^{-1} will nearly double the air drag that a skier experiences; with more severe wind conditions skiers must often adjust body positioning and/or technique to maintain performance. Despite head winds, a skier must be able to generate propulsive force, so technique cannot be severely altered. However, some lowering of the body through trunk and neck flexion is one strategy which may modestly reduce air drag. Another strategy involving drafting behind a leading skier becomes increasingly advantageous as wind speed increases. Similar to drafting in cycling or running, a skier trailing close behind another experiences reduced air drag because of a reduction in front–back pressure difference. The trailing skier, when close enough, can be skiing within a low pressure region behind the leading skier. Based on cycling experiments, drafting skiers may benefit from reductions of drag force as much as 25–30%.

Snow drag force

Gliding across snow is one of the joys of cross country skiing. The physics of ski–snow interaction is what makes low resistance gliding on snow possible. The physical processes involved bring together a complex interaction of liquid and solid water, ski-base

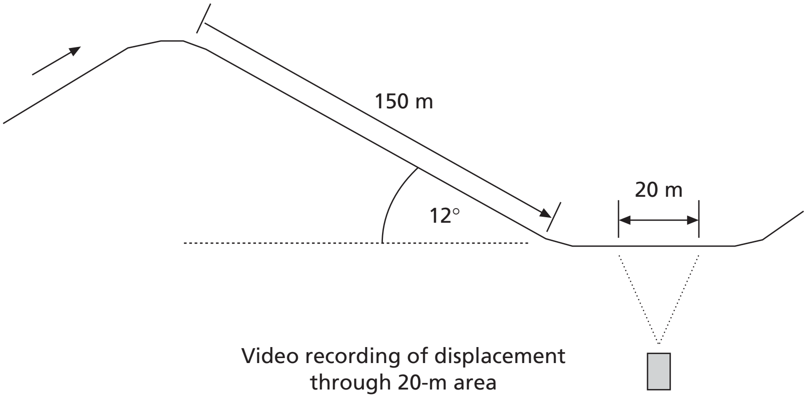

Fig. 2.31 Glide testing of Olympic skiers was carried out during the men's 50 km race at the Albertville Winter Olympics. The section of the race course involved a steep straight downhill of about 150 m length. At the bottom, as skiers glided across a flat, speed was determined using video motion analysis.

material, ski waxes, ski-surface roughness, snow-surface compaction, as well as air and snow temperature, radiant exposure, snow contaminants and probably other factors. The complexity of factors involved in studying ski glide characteristics makes determination of the relationships between the factors a challenging undertaking. Currently, these relationships are only partly understood. However, what is clear to any experienced skier is the wide range of snow drag forces that can be encountered during a season of skiing. Explaining the physics behind snow and ski friction is beyond the scope of this handbook; however, there are several monographs that can be referenced if the reader wishes to delve into the details of meltwater lubrication and other esoteric topics relevant to skis and snow (e.g. Colbeck 1992, 1994 and 1997). This section deals with snow drag forces and performance.

Ski-races often are decided by small time differences of a few seconds which seem almost insignificant across the span of 2 or more hours typical of long competitions. Small differences in snow drag force can easily result in minute differences in performance. For example, imagine a 10-km skating race in which a certain skier can maintain a 5 $m \cdot s^{-1}$ average speed, finishing the race in 2000 s. With a typical coefficient of friction for skis of 0.05, the skier would experience a snow drag force of about 35 N; air drag would be somewhat less, about 10 N. Thus, the skier would be working against 45 N of combined drag force throughout the race. At the average speed of 5 $m \cdot s^{-1}$, this would require mechanical power of about 225 W and this would in large part determine the skier's metabolic rate. Now consider the effect of a 5% increase in the coefficient of friction for the skis. Snow drag would increase proportionally and total drag force would increase as well. If skiing at the same speed, metabolic cost for the skier would increase by almost 4%; if skiing at constant intensity (225 W), speed would have to be reduced to about 4.86 $m \cdot s^{-1}$ which would increase the skier's race time to about 2058 s—almost a minute slower!

The 5% change in coefficient of friction suggested in the example above is not large and probably would not be detectable by most skiers were they to ski two pairs of otherwise identical skis which differed only in this small amount but the effect on performance is substantial. To assess how influential snow drag force may be during ski competitions, data were collected on glide speed of Olympic skiers in the men's 50 km race at the Les Saisies venue near Albertville, France in 1992. Figure 2.31 illustrates the terrain in the race where speed measurements were made. Skiers came over the crest of a hill, skated several times and then settled into a tight tuck position in straight well-set tracks. They glided across a flat section at the bottom of the downhill and maintained a tuck position until well past the measurement zone. Video was used to record skier movement through the zone. Subsequent analysis determined skier time to traverse the 20-m zone from which glide speed was calculated. Average glide speed across the flat was about 15 $m \cdot s^{-1}$. As can be seen in Fig. 2.32, glide speed was negatively related to finish time in the race; faster skiers overall in the race were also faster in downhill ski glide.

Analysis of these glide data through modelling of the aerodynamic characteristics of skiers, combined with gravitational and snow drag forces, yielded rather

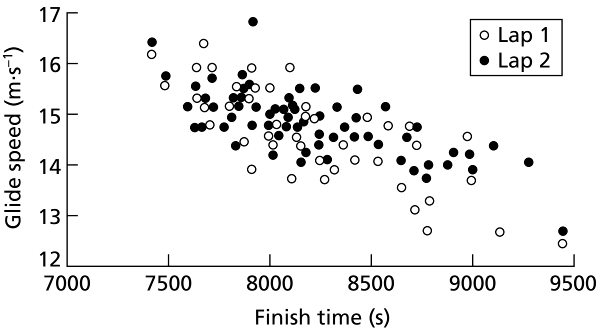

Fig. 2.32 Glide speed and race finish time were recorded for participants in the men's 50 km race at the Albertville Winter Olympics. Glide speed was strongly related to finish time for each lap of the race. Faster skiers in the race also were faster through the glide test. Subsequent modelling analysis of skier downhill glide found little relationship of glide speed to skier mass. Glide speed was most strongly influenced by snow drag force. (Graph adapted from Street & Gregory 1994.)

enlightening results. Four factors influenced glide speed downhill: skier mass, starting speed, air drag and snow drag. Systematic manipulation of these factors in a computer model of downhill glide allowed evaluation of their relative importance. Mass and ski frictional force were found to have the greatest potential influence on glide speed while air drag force differences because of tucking technique and initial speed at the top of the hill were less influential on glide at the bottom of the hill. Correlation analysis using each skier's characteristics found skier mass to be unrelated to performance in this race. Thus, snow drag force was by far the most influential factor determining downhill glide speed in this 50 km race. While some of the variability evident in the scatter of data points in Fig. 2.32 is caused by other factors, it is clear that ski–snow frictional forces probably had a major effect on glide speed in this race. While downhill skiing accounts for a relatively small fraction of total time for most cross country races, glide and snow friction affect ski performance on other terrain as well, particularly in skating races. Thus, it is likely that ski and wax choices affecting snow drag force have a significant role in determining race performance even at the elite level in races as important as the Olympics. World Cup skiers of many teams have access to the best skis available and the help of professionals dedicated to ski preparation and waxing. It is surprising to find such substantial effects on performance because of ski friction under these circumstances. For lower level competitors, the effects can be expected to be more pronounced than observed for the Olympians of this study. Thus, the importance of minimizing snow drag forces through careful ski preparation and waxing cannot be overemphasized.

Ski pressure distribution

Newton's third law deals with 'action–reaction'. A force applied through the ski to snow is paired with a reaction force of equal magnitude of snow on ski transmitted to the skier. While it may be convenient mathematically to think about such forces as having a single point of application (e.g. to the foot of the skier), such simplification would ignore an aspect of ski design which has important implications for skier performance. Skiers generate external force through muscle activity and body motions which are transmitted to skis and poles which in turn transmit the reaction forces to the skier. Force applied to a ski is transmitted to snow across the large bottom surface area. Pressure is a measure of how force is spread out over a surface and is described in units of force per area. A force applied to the top surface of a ski at the binding is transmitted to snow all across the bottom surface but in characteristic non-uniform patterns. Small areas near the tip or tail of a ski may carry considerably more force than do other regions. Because snow is a deformable material which responds in a manner which depends in part on the pressure applied to it, regions of high pressure under a ski are likely to penetrate more deeply into a snow surface than do low-pressure regions. Snow deforms inelastically and returns little energy to a ski. Such deformation heats up snow through energy loss to the ski which ultimately decreases glide. Therefore attention to pressure distribution patterns of skis is of interest for purposes of improving performance.

Skating skis involve complex designs which must not only glide well but must have sufficient torsional stiffness to resist twisting about the ski's longitudinal axis during edging under load. In addition, stiffness of a skating ski's camber must be sufficient to enable straight tracking in the forward direction. These some-

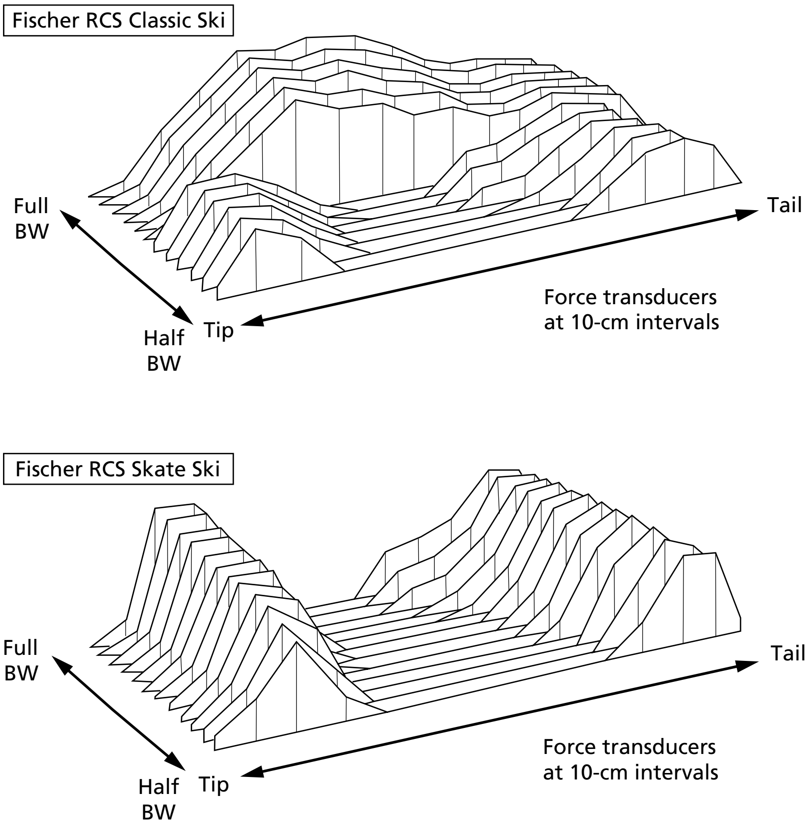

Fig. 2.33 Pressure distribution for a skating and a classical ski. Note that pressure distributions change under each ski as loading changes from half to full body weight. The skating ski remains lightly loaded in the mid-region at body weight, while the classical ski compresses the mid-region so that wax can grip the snow during kick to the ski. (Modified from pressure distribution graphics from Eagle River Nordic: http://www.ernordic.com/skidata.htm)

times competing demands are what manufacturers grapple with in each new design. Typical pressure distribution patterns for skating and classical skis are shown in Fig. 2.33. The patterns clearly change with magnitude of loading. It is these rather large-scale overall patterns which determine a ski's tracking, edging and stability characteristics.

The classical ski has an additional challenge required for good performance. The mid-region must be sufficiently stiff so that under moderate loading very low pressure is observed in the region. This allows kick wax in the mid-region to remain unloaded and not drag along the snow surface when a skier is gliding on one or both skis. However, with larger forces above body weight magnitudes, the classical ski mid-region is compressed against the snow allowing good adherence of grip wax with surface snow. During this compression when static frictional force is greatest, a kick from the momentarily static ski is made. Thus, appropriate matching of skier weight with ski stiffness is crucial for optimal generation of propulsive force.

The full ski pressure patterns of Fig. 2.33 certainly have some influence on pure glide characteristics. One would expect that extremely stiff skis with very high pressure at tip and tail of the ski would cause more deformation of snow, plowing it in front of the ski, than would softer designs which might allow the ski tip to ride up and over softer snow. While these relationships have perhaps been studied by manufacturers, the details are confidential and not available to the public.

Moving from the large-scale pressure patterns which affect ski handling, a more localized pressure distribution could in principle be measured as well. On a scale of several centimeters, it is likely that pressure differences also affect localized drag forces acting on the ski. A small localized high-pressure region will also deform the snow surface and increase snow drag. Flattening a ski to minimize localized fluctuations of pressure in the longitudinal direction is an arduous task with hand tools. However, stone grinding instrumentation and experienced technicians to run it have become more widely available in recent years. These can reduce centimeter-scale irregularities of a ski's pressure distribution while introducing millimeter-scale roughness ('structure'). This is thought to enhance glide through better matching of snow crystals, surface asperities and water droplet adhesion which result in drag force acting on a ski surface at the microscopic level.

Main points to remember about drag forces and ski pressure distribution

- Mechanical work for a skier is largely against air and snow drag forces. Minimizing these forces is an essential aspect for performance improvement.
- Air drag force for a given speed depends on a skier's shape (body position) and size. Adjusting body position to decrease frontal area and streamline body shape are strategies that enhance glide speed down hills and when encountering head winds.
- Snow drag force depends on snow temperature, crystal shape, ski-base material, base roughness, wax and other factors. Minimizing snow drag is particularly important in skating where a ski continues gliding during propulsion.
- Small differences in ski friction, which may not be detectable by a skier, can affect race times by several per cent. Minimizing ski coefficient of friction during glide is thus essential to optimal race performance. At the elite level, the fastest skiers have the best prepared skis.
- Pressure distribution across a ski's base determines much about how the ski handles and how fast it will be. Large-scale mapping of pressure should change smoothly from tip to tail of a ski under moderate and heavy loading. On a small scale, pressure peaks along the base should be minimized to reduce drag as a ski glides over snow.

Technique optimization and economy

Human locomotion mechanics and physiology have been of interest to scientists from the beginnings of science. A question that has attracted attention in recent decades is relevant to our discussion of ski biomechanics. Humans naturally walk at slow speeds and run at faster speeds. When asked to move through a range of speeds from slow to fast, humans transition from walking to running at about 2 $m \cdot s^{-1}$. What mechanical and/or physiological factors explain this human walk–run transition point? At first glance, the answer seems intuitively obvious: the walk–run transition point must be the speed where the metabolic cost of walking exceeds the cost of running. However, measurement of this 'crossover point' of walking and running metabolic costs is somewhat lower than is actually observed. Other factors might also be involved. Various researchers have found evidence for kinematic, muscular and force 'triggers' of the walk–run transition or perhaps a more global dynamic system response using many input factors. A comprehensive explanation of the human walk–run transition point has not currently been formulated.

In skiing, various locomotion patterns are used by skiers as they encounter terrain and environmental conditions that affect the speed and metabolic demands of moving over snow. In racing, where competitors operate at relatively constant metabolic rates throughout a race, terrain largely determines a skier's choice of technique. As terrain varies, skiers transition from double pole with kick to diagonal stride or from Open Field skate to V1 and back again in a rather unconscious manner not unlike the walk–run transition over ground. What factors trigger these transitions? Are there clearly advantageous techniques to be used on the flat, on moderate uphills or downhills? These questions are probably no easier to answer for researchers than those dealing with the walk–run transition and unfortunately we have less evidence with which to work, but there are some clues to suggest under what conditions certain techniques may be advantageous.

Skating technique and terrain

A study comparing skiing speed with V1, V2 and Open Field skate with elite skiers on varied terrain of a 3-km course (Bilodeau *et al.* 1991) found that race pace skiing had similar metabolic demands (based on heart rate) for each technique. Further, similar speeds were observed for the techniques with a trend in the data suggesting that V1 was slightly faster uphill and Open Field slightly faster downhill. A follow-up study (Boulay *et al.* 1994) had skiers skate at maximal effort on various slopes using the three skating techniques. Little difference in skating speed was observed for moderate terrain up to 6% uphill. However, on steeper uphills V1 skating was clearly faster. Figure 2.34

shows the speed, cycle length and rate relationships for the varying slopes.

These responses shed light on the distinct differences of the three skating techniques. Across quite varied terrain, very similar skating frequencies were used for a given technique and these were dramatically different amongst the three techniques. V1 skate is consistently much higher frequency than Open Field and V2 skating. Do these results match with typical technique choices made by racers in varied terrain? Yes, V1 skating *is* usually the technique of choice on uphills, but on easy rolling terrain skiers are more likely to ski with Open Field or with V2 techniques. The research findings suggest that V1 may well be as fast; why is it not the technique of choice on flat terrain? The full answer is unknown but, like the walk–run transition, metabolic comparisons of the techniques do not provide an explanation. Perhaps the distribution of effort from arms to legs is sufficiently different in the V1 and Open Field, for example, that alternating technique where possible becomes advantageous. Optimizing performance in a race involves not only momentary choices of technique, but longer duration choices of effort in uphill and downhill terrain and on overall race pacing. Mechanical characteristics of techniques, a skier's physiological attributes and even ski equipment responses combine in a complex manner that is rapidly assessed by skiers as they smoothly transition between techniques going uphill to downhill and back up. However, we have rather limited understanding of the nature of that internal calculus.

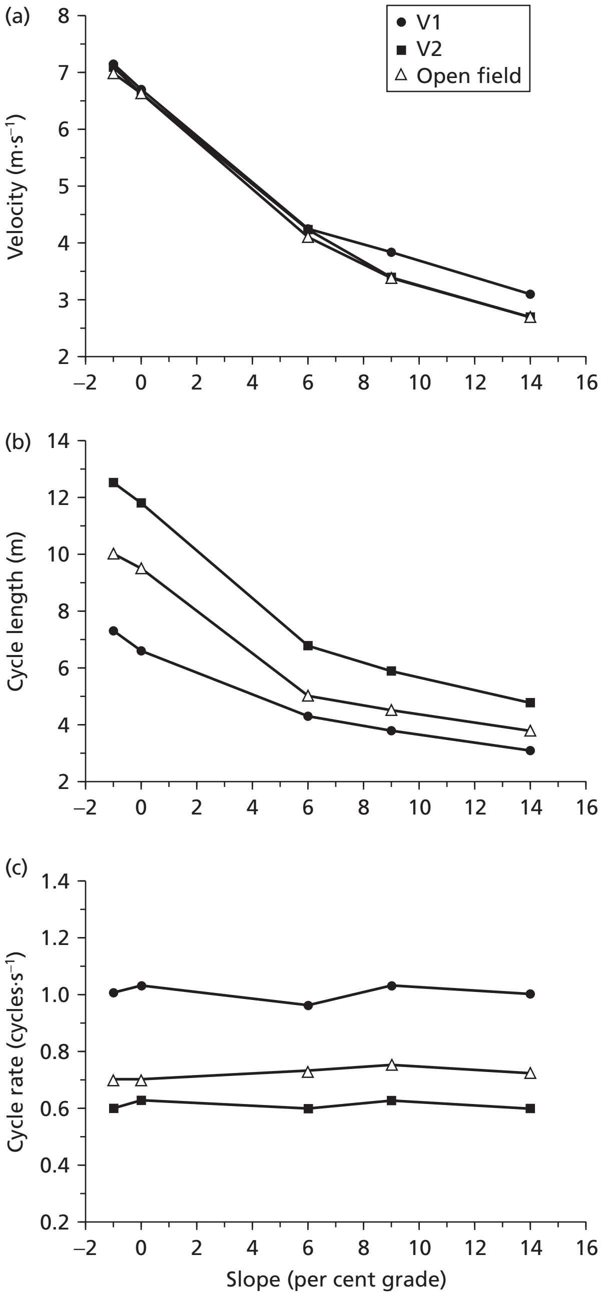

Fig. 2.34 Comparison of V1, V2 and Open Field skating characteristics on varying slopes. On each slope skiers skated at maximal effort. Video was used to determine (a) velocity, (b) cycle length and (c) rate. The skating techniques were equally effective on – 1, 0 and 6% slopes but V1 was faster on steeper uphills. Note that cycle rate (frequency) stayed nearly constant for each technique across the range of slopes. (Adapted from Boulay *et al*. 1995.)

Cycle characteristics and performance

Stride length and frequency are kinematic variables that together determine skiing speed. Interaction of these characteristics depends on terrain, intensity (metabolic cost), snow conditions and, as we have seen above, on technique choice. Under most conditions, control of skiing speed is determined by a skier's stride frequency while stride length remains relatively constant (Fig. 2.19). Each technique seems to have its own frequency at maximal speed which also remains relatively constant across terrain (Fig. 2.34). How does a skier's self-determined stride length and frequency relate to race performance?

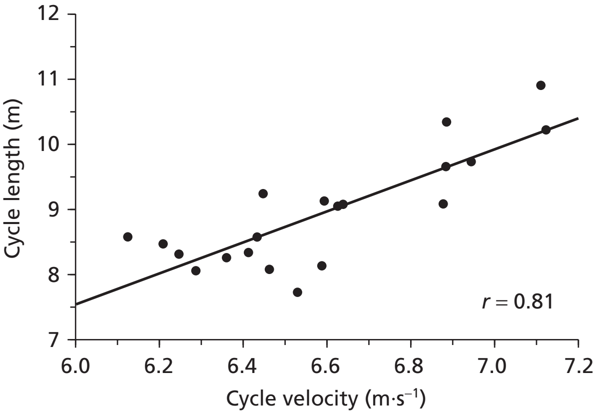

Fig. 2.35 Cycle length vs. cycle velocity in double poling. Data were obtained during the women's 30 km race of the 1994 Winter Olympics in Lillehammer. Faster skiers had greater cycle lengths than slower skiers. Similar patterns have been observed for skiers using other techniques and on other terrain.

If, instead of looking at an individual skier's speed–frequency–stride length relationship, we look across skiers and compare cycle characteristics, a quite different picture emerges. Figure 2.35 shows cycle length of Olympic skiers in the women's 30 km race (1994) while double poling on a moderate downhill. Faster skiers through the measurement site were generally those with greater cycle lengths. Double poling frequencies of these skiers were not significantly related to skiing speed. This pattern of skier speed related to stride length has been observed with both skating and classical techniques and on uphill, flat and this moderate downhill terrain. In general, the fastest skiers as well as slower racers stride with rather similar frequencies for a given condition, but the fastest skiers consistently have greater stride lengths than slower skiers. Putting these relationships together, skiers control speed at any point primarily by adjusting stride frequency but faster skiers obtain their speed advantage by greater stride length. At any point in a race, a skier should focus on stride frequency as the mechanism of speed control. However, in training it is stride length which must be increased through technique, strength and other preparation focused on this key characteristic.

What factors enable the fastest skiers to generate longer strides than slower skiers? This is a central question to which biomechanics can contribute at least part of the answer. Clearly, the forces acting on a skier determine motion characteristics. As we have seen in our discussion of snow drag forces, the fastest skiers often have skis with less snow drag. This advantage may come from the ski's overall pressure distribution, from its surface preparation and from its waxing. The fastest skiers probably have the fastest skis. This partly accounts for the greater stride lengths fast skiers exhibit.

Technique also affects forces acting on a skier. Effective technique generates propulsive force without increasing drag forces, without increasing side-to-side motion in skating and without increasing metabolic demands. Effective technique requires equipment well matched to a skier's height and weight so that optimal body positioning can be obtained in poling and so that effective thrust can be obtained from the skis. Determining equipment characteristics which optimally match a skier's characteristics is a challenge to which biomechanics can contribute relevant data but which ultimately requires the insights that coaches and athletes bring together.

Main points to remember about technique optimization and economy

- Technique transitions occur with changes of terrain, conditions and skier capacity.
- Little metabolic cost difference has been found for V1, Open Field, and V2 skating on flat terrain. V1 skating becomes advantageous for increased speed as uphill slope increases.
- At race pace, stride frequency is relatively constant for a given technique across varied terrain. V1 skating is higher frequency than Open Field and V2 techniques.
- Faster racers have been found consistently to ski with greater stride length than slower skiers, while stride frequencies are similar across the spectrum of race performance. Increased stride length through improved physical capacities and ski characteristics will advance performance.

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Chapter 3

Training for cross country skiing

Principles of training

The training of athletes is based on the stress theory which includes the stages of alarm reaction and acute adaptation to the demands of exercise, resistance development and fatigue–exhaustion. Physical exercise is a stimulus (stress) to which the body responds by the so-called alarm reaction: muscles are recruited, hormones are secreted, energy yield is increased, functional reserves are mobilized and defence mechanisms are activated. These responses are mediated by both the neural and humoral mechanisms related to the function of the autonomic nervous system (ANS): the activation of the hypothalamus, hypophysis, sympathetic nervous system (SNS) and stress hormone secretion (e.g. catecholamines, cortisol). As a result, the body acutely adapts to the requirements of the exercise to resist the disturbance of homeostasis induced by the exercise (negative feedback) as well as possible.

Repeated exercise stress leads to training-induced adaptations resulting in an improved capacity to resist the disturbance of homeostasis in different cells, tissues and organs: resistance development = training effect. Muscles and heart increase in size, and heart rate during constant load exercise is lower than before the period of repeated exercise stress. If the stress of training is too high, the body enters the stage of acute short-term fatigue and/or chronic long-term fatigue and exhaustion, and injury, illness or overtraining syndrome may develop.

Physical training is only one stressor to which the body has to respond. The non-training stressors or stimuli that induce stress are physical environment (temperature, humidity, oxygen content, time zone shift); psychosocial environment (personal and situational factors); primary and secondary needs (rest, sleep, nutrition, sexual instinct). The body integrates the effects of all stressors and responds to the total stress of the body. Depending on the personal and situational stress factors of the athlete, responses to the same training exercises are not always the same.

The overload principle and progression of training load

The overload principle states that if the stress of exercise or training is not sufficient to threaten the homeostasis of cells, tissues and organs, there is no training effect. Therefore, the training load must be increased to attain further adaptation. Athletes are sometimes so well-trained that it is difficult to increase exercises to disturb the homeostasis and, consequently, performance is not improved. The training effect may even be negative: performance capacity may decrease if training load decreases.

The progression of training load means that the intensity, duration, frequency or some other aspect of training has to be increased progressively. Progression can be induced by using different methods to overload the body: by increasing intensity of exercise, duration of exercise, number of repetitions, frequency of training sessions, volume of training, etc. The term ‘training load’ is used as a combined measure of one training session: load = duration × intensity. The term ‘total training load’ is the sum of all training loads over a given period of time: total training load = duration × intensity × frequency of training sessions.

Fatigue–recovery

Fatigue has been defined as an inability to maintain a given force or exercise intensity. In cross country skiing fatigue may be caused by energy depletion (e.g. glycogen, blood glucose); metabolite accumulation (lactic acid and increased acidity); inadequate O_2 delivery (total haemoglobin mass, maximal cardiac output); disturbances to homeostatic functions (electrolyte levels, fluid balance); or it may be of neuromuscular origin (decreased central recruitment and peripheral force production). Signs and symptoms of fatigue usually disappear within 24–48 h.

If the next training session is carried out before full recovery or if the training exercise as such is too demanding, fatigue may start to accumulate and stress

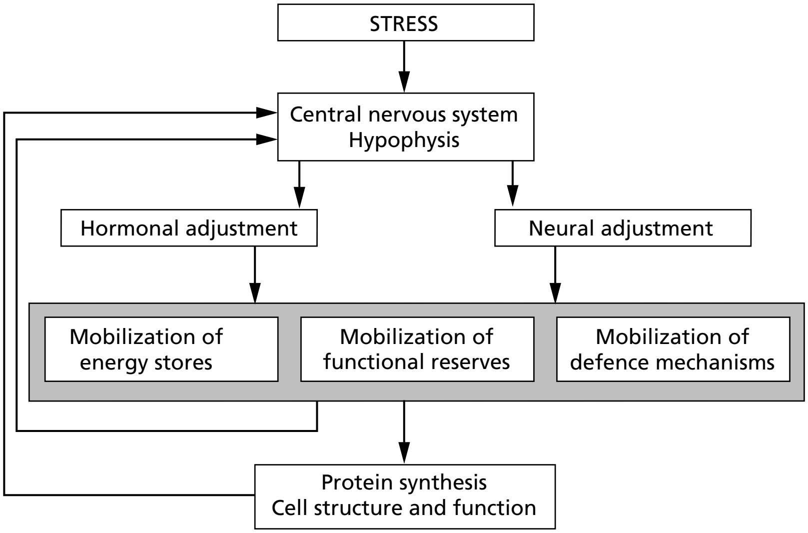


Fig. 3.1 Schematic description of the general adaptation mechanisms that influence the responses to exercise and training.

response is not turned off: muscle glycogen stores decrease day by day, sympathetic activation and heart rate at rest is increased, etc. Consequently, the balance between training stress and recovery measures is disturbed.

Typically changes in blood cortisol and testosterone concentrations have been used to describe the balance between catabolic and anabolic reactions in the body. After demanding training they are almost always recovered in 1–2 days. There may also be sublethal or lethal damage of muscle fibres during demanding training because even elite cross country skiers have demonstrated muscle enzyme leakage to blood after a 50-km ski-race. Recovery from sublethal muscle damage may take several days and if muscle fibres are lethally damaged growing of new muscle cells around nuclei may take a couple of weeks. Neuroendocrine and autonomic functions are usually recovered in 1–2 days after typical endurance training sessions.

Athletes and coaches speak mainly about training programmes and training exercises; however, almost all training adaptations occur during recovery. For instance, during training, protein breakdown is increased and protein synthesis decreased and end-products of protein metabolism are secreted to urine. During recovery, the turnover of amino acids and proteins is high but the synthesis is faster and greater than breakdown and new structural and functional proteins are synthesized based on the 'information' obtained during training (Fig. 3.1). If the neuroendocrine and autonomic functions have not recovered, protein synthesis may be disturbed.

Adaptation process

The process of adaptation includes stimuli from training exercise, mediating mechanisms between and within tissues, activation of protein synthesis and production of new proteins in muscles, heart, lung and brain. The adaptations at muscle tissue level are related to force and tension of muscles, electromyographic (EMG) activity, recruitment of fibres, stretch of muscles and tendons, humoral stimuli, etc. Similarly, adaptations in heart are most probably related to the stretch and tension of heart muscle as well as to humoral stimuli. In the brain the adaptations are most probably related to neural impulses to muscles and to feedback from force–tension, EMG activity and neural impulses from muscles and tendons to the brain. Humoral stimuli within the brain and to the brain from blood pressure and the oxygen content of blood modulate the adaptation in the brain.

The order of training adaptations is not clear but it could hypothetically be the following. First, the skier has to increase the recruitment of muscles during maximal and submaximal training exercises to attain a higher performance velocity than before. Then he or she has to keep up that new velocity (and new force level) for a longer period of time. When muscles are more/longer activated, relevant enzymes are more activated and their concentration is increased within hours to days. The increased force production, work done and oxygen utilized require an increased blood flow to muscles that leads to adaptation in capillaries and circulation within days to weeks. Increased demands for higher oxygen transport and cardiac output induce functional and structural changes in the heart, lungs and blood (e.g. increased myocardial blood flow, increased total haemoglobin mass, increased maximal ventilation) within a few weeks. Finally, maximal cardiac output, maximum oxygen uptake and endurance performance are improved.

Overreaching and periodization

Normal overload training means that a skier has one demanding training session after which he or she recovers in 6–24 h and performance is improved (see Fig. 5.1). Sooner or later skiers observe that it is difficult to disturb the homeostasis by doing only one demanding training session in order to improve performance capacity. Overreaching means that a skier intentionally increases the total training load for a short period of time (a few days or even weeks) to induce a longer/greater disturbance of homeostasis so that further training adaptation can be attained. Recovery between training sessions is not complete, fatigue accumulates and the overreaching period leads to a short-term decrement in performance capacity (Fig. 5.1). Recovery from overreaching with improved performance may take 2–5 days. If overreaching is continued for a longer period, fatigue may accumulate and a skier may enter the process of overtraining (see Figs 3.2 and 5.1 and Chapter 5).

The time required to attain the different training effects in the different determinants of endurance performance is surprisingly short if training induces disturbances in homeostasis. Functional adaptations are faster than structural adaptations. If the total training load is increased and kept at that level, the adaptation to that training load is attained in a period of 3–4 weeks. Blood lactate concentration during constant load submaximal exercise decreases considerably during the first 2 weeks and after 3–4 weeks no further decrease is observed if the training load is kept the same (see Åstrand & Rodahl 1986). A similar training response has been found in the increase in maximum oxygen uptake. For further training effect more demanding total training load is needed. Most of those studies have been carried out on relatively untrained persons. However, when the total training load of endurance athletes was progressively increased during an experimental overreaching and overtraining period from their normal training load (up to 50% increase in total training volume and 250% increase in the volume of high intensity training in 7–8 weeks), the $\dot{V}\mathrm{O}_{2\mathrm{max}}$ increased and 30-min performance improved significantly within 4 weeks (Fig. 3.2). The figure also shows that too lengthy and enhanced overreaching leads to a decrease in performance that in turn leads to athletes showing overtraining symptoms.

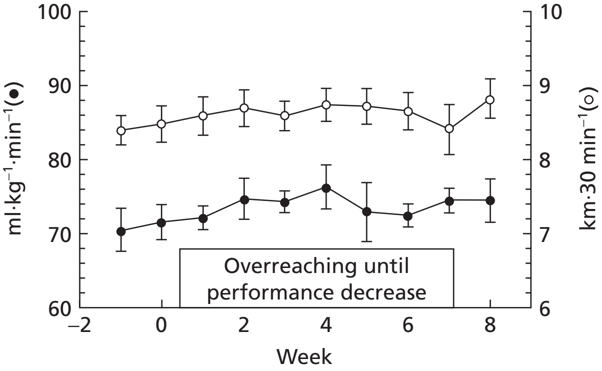


Fig. 3.2 Treadmill $\dot{V}\mathrm{O}_{2\mathrm{max}}$ ($\mathrm{ml\cdot kg^{-1}\cdot min^{-1}}$) and performance ($\mathrm{km\cdot 30\ min^{-1}}$ on treadmill) changes during experimental overreaching period in three elite endurance athletes whose total training load was increased weekly by increasing both the total training volume and the volume of intensive training. Highest $\dot{V}\mathrm{O}_{2\mathrm{max}}$ was individually attained on weeks 3 and 4 and longest distances were individually run on weeks 2, 4 or 6. Significant decrease in mean $\dot{V}\mathrm{O}_{2\mathrm{max}}$ was seen on week 5 while performance decreased significantly 2 weeks later when other overtraining signs and symptoms were also recorded. In control athletes no changes were observed.

Recent studies suggest that significant improvement in many functional characteristics of athletes can be attained in 2–4 weeks of overreaching. When using such overreaching periods the different schedule of functional and structural adaptations has to be taken into account. For instance, heart rate during constant load submaximal exercise decreases in 2–4 weeks. Because the growth in heart structure and size takes a longer time than the decrease in submaximal heart rate, the decreased heart rate is partly caused by functional adaptations in contractility and autonomic activation of the heart. In training, a balance between structural and functional development should be sought; after improving the functional characteristics by an overreaching period, a certain period has to be reserved for establishing structural adaptations.

Typical training periods of cross country skiers are an altitude training period, a volume training period during the first weeks of ski-training on snow, a strength training period, an intensive training period, etc. (see later parts of this chapter). Therefore, a stepwise alternating improvement of different specific (limiting) characteristics is an essential part of the training of cross country skiers. In periods of 2–4 weeks, emphasis could first be put on increased muscle recruitment and force production, then on central circulation and oxygen transport and on fat utilization during the next period.

Specificity of training

The specificity of training means that only those characteristics in only those muscles, tissues and organs that are overloaded during training will be improved. This principle could be interpreted that the closer the training exercise is to the race performance the better is the training effect, but the principle of specificity is not as simple as that. Training only at race pace for the duration of race is not necessarily the best way of training. More specifically, race performance may be more easily improved if one or two of the most important (limiting) determinants of race performance are trained at a time using the overload and overreaching principles.

Specificity of inducing either central or peripheral adaptations is also important in training for cross country skiing. Training usually induces both central and peripheral adaptations. Figure 3.3 shows that running training improves $\dot{V}O_{2max}$ of running and cycle training improves mainly $\dot{V}O_{2max}$ of cycling. The improvements are brought about by both central (cardiac output, oxygen transport) and by peripheral adaptations (arteriovenous O_2 difference, muscle capillarity, oxidative enzymes). The peripheral specificity can be seen in the greater improvement in the training-specific $\dot{V}O_{2max}$ test as compared to the non-training-specific $\dot{V}O_{2max}$ test. The influence of smaller muscle mass during cycle training and central specificity can be seen in the small improvement of non-specific running $\dot{V}O_{2max}$ test compared to the effect of running training on cycling $\dot{V}O_{2max}$.

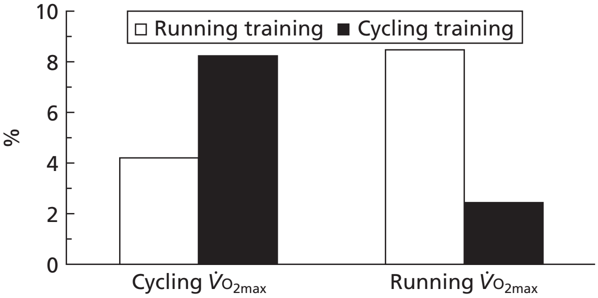


Fig. 3.3 Effects of running and cycling training on running and cycling $\dot{V}O_{2max}$. Peripheral specificity can be seen in the greater improvement in the training-specific $\dot{V}O_{2max}$ test as compared to the non-training-specific $\dot{V}O_{2max}$ test.

Detraining–retraining

Disappearance of adaptive responses occurs as quickly as their development; functional adaptations disappear quickly and structural adaptations slowly. If the total training load decreases, the attained functional adaptation will also decrease. Adaptations related to structural changes (heart size, maximal cardiac output, $\dot{V}O_{2max}$) can be maintained more easily by reduced training load. In cross country skiing the problem is the oxidative capacity of muscles and fat utilization. During the racing period they decrease in a few weeks while $\dot{V}O_{2max}$ can be maintained by racing and decreased training volume. The decrease in the oxidative capacity seems to be faster in the arm and upper body muscles than in the leg muscles. The impaired oxidative capacity of muscles most probably explains the decrease in lactate threshold (LT) and respiratory compensation threshold (RCT) of some cross country skiers during the winter racing season.

Findings of studies on runners also support this; 2 weeks' break in training decreased $\dot{V}O_{2max}$ by 4% while succinate dehydrogenase (SDH) activity and prolonged work capacity as time to exhaustion decreased by 25%. After 2 weeks' retraining $\dot{V}O_{2max}$ had returned to the initial level while SDH activity and prolonged work capacity were still worse than before detraining. In elite athletes the time to attain the predetraining $\dot{V}O_{2max}$ and prolonged work capacity may be longer than the period of detraining.

Model for cross country ski-training

The potential limiting factors of cross country ski performance (see Chapter 1) can be classified into two main categories:

1 factors related to oxygen transport and energy utilization; and

2 factors related to neuromuscular function and economy of skiing.

This classification fits well with a new model for endurance training that has recently been presented and which is used in this handbook. The new model takes into account that the neuromuscular and muscle power factors may also limit endurance performance and that strength training is also important for endurance athletes (see Fig. 1.11). This model classifies the training into two categories: training for improving aerobic endurance, and training for improving neuromuscular endurance.

Traditional endurance training is mainly planned for improving oxygen transport and energy utilization by improving the cardiorespiratory system, blood volume and total mass of haemoglobin, oxidative enzymes as well as fat utilization. After training glycogen depletion is slower and blood lactate concentration during constant submaximal exercise decreases and $\dot{V}O_{2max}$ and fractional utilization of $\dot{V}O_{2max}$ are improved. Anaerobic components of endurance training increase anaerobic energy yield, buffer capacity and resistance to acidity and thereby anaerobic work capacity. It is expected that anaerobic training also improves some neuromuscular characteristics.

The training for improving neuromuscular endurance recognizes the importance of strength training, technique training and power training for improving endurance performance. It is well-known that heavy resistance strength training increases both neural recruitment and hypertrophy of muscles. Sprint training and explosive-type strength training (force–velocity-type training) also increases recruitment and activation of muscles, while muscle hypertrophy is much less than during heavy resistance strength training. Explosive-type strength training also improves the storage and recoil of elastic energy.

Strength and sprint training for improving neuromuscular endurance requires using higher forces and velocities than the body and muscles are used to. When the neuromuscular ability to ski at a higher pace has been developed, the economy of skiing at that velocity should be improved by polishing the memory engram of that performance in the central nervous system (CNS). Finally, the more economical skiing performance must be maintained for a prolonged time and finally during the whole race performance by improving neuromuscular fatigue resistance. Traditional anaerobic training may have improved some aspects of neuromuscular endurance but the volume of anaerobic training and training at race pace has been small. The new model emphasizes that training exercises for improving maximal anaerobic skiing power, techniques and economy at race pace are an essential part of the training plan.

Main points to remember about principles of training

- The overload principle states that a training session is beneficial only if it threatens the homeostasis of cells, tissues and/or organs.
- The training load has to be increased progressively to attain further adaptation and performance improvement.
- The training of elite skiers includes periods of overreaching when the total training load is intentionally increased for a short period of time (a few days or even weeks) to induce a longer/greater disturbance of homeostasis so that further training adaptation can be attained during the consequent recovery period.
- The training effect is built up during recovery after training based on the ‘information’ obtained during training.
- Specificity of training means that only those characteristics in only those muscles, tissues and organs that are overloaded/stressed during training will be improved. Specificity of inducing either central or peripheral adaptations is also important in training for cross country skiing.
- The new model for cross country ski-training emphasizes the importance of training for both aerobic and neuromuscular determinants of endurance performance.

Training for aerobic endurance

The most important factor for improving the aerobic endurance of children, untrained persons and young

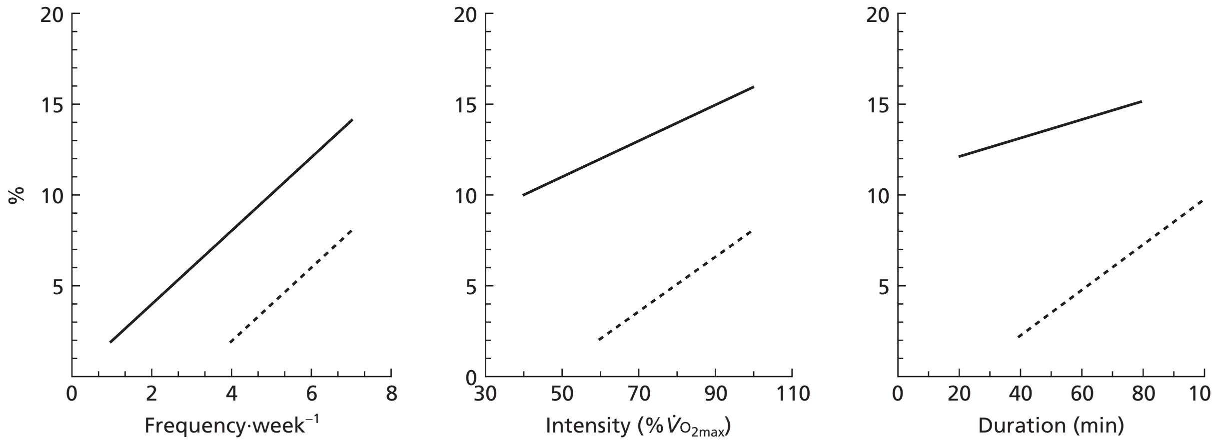


Fig. 3.4 Effect of training frequency and intensity and duration of exercise on the development of $\dot{V}O_{2peak}$ of less trained (solid line) and well-trained (dashed line) persons and junior skiers.

skiers is training frequency. The significance of training intensity is less at the beginning of training but more intensive training usually leads to slightly higher increase in $\dot{V}O_{2max}$. Along with improved $\dot{V}O_{2max}$ the importance of training intensity is increased. Similarly, at the beginning of training the duration of the training session is relatively unimportant but the longer the duration the higher the increase in $\dot{V}O_{2max}$. During the first weeks and months of training, $\dot{V}O_{2max}$ may improve by 10–20%. Thereafter, $\dot{V}O_{2max}$ increases considerably less, and the frequency, intensity and duration of training sessions all become important determinants of good training (Fig. 3.4).

Experience by trial and error has shown that it is impossible to train seven or more times per week at 80–100% of $\dot{V}O_{2max}$ for 60–80 min. Therefore, the training programme of endurance athletes consists of alternating various types of training exercises through the week or some other training entity so that only one or some of the determinants of endurance performance are trained at a time in a single training session.

Training for improving energy supply and utilization is specific to the training intensity. The dominant energy supply process will be developed. Training at race pace is often thought to give the best training stimulus to improve the energy supply for race performance. However, all the different energy supply systems necessary for skiing performance should also be trained separately by using specific training intensities and durations. Fat utilization can be improved by prolonged training exercises lasting for 1 h or more at low intensity around lactate threshold. Oxidative capacity can be increased selectively in fast twitch (FT) and slow twitch (ST) fibres depending on the intensity and duration of exercise. The amount of active muscle mass determines how great the training effect is on the oxygen transport capacity of central circulation (heart and cardiac output) and how much peripheral adaptations occur.

Training for improving $\dot{V}O_{2max}$ and cardiorespiratory function

Influence of muscle mass

The most important factor in improving whole body $\dot{V}O_{2max}$ is that a great muscle mass including upper and lower body muscles is recruited. The great muscle mass guarantees that stroke volume is high even at low exercise intensity and that high cardiac output and $\dot{V}O_2$ are easily attained during the training exercises. If emphasis is also put on the development of peripheral determinants of $\dot{V}O_{2max}$ then sports-specific muscles should be recruited. The best training modes are uphill cross country skiing, uphill ski-walking or ski-striding using ski poles and uphill roller skiing using slow roller-skis. During mountain biking and uphill running almost as high muscle mass is

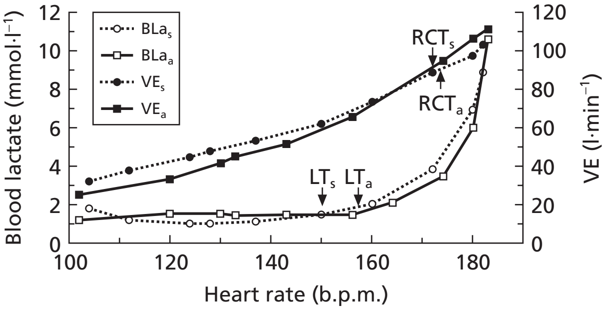


Fig. 3.5 Blood lactate concentration (BLa) and lung ventilation (VE)–heart rate curves of a several times gold medal female skier in the spring (subscript s) and autumn (a) treadmill pole striding test. Lactate threshold (LT) and respiratory compensation threshold (RCT) had improved and higher heart rates were prescribed for low-intensity and fast distance training as well as for $\dot{V}O_{2max}$ training. (From Kantola & Rusko 1985.)

activated, but the effect on whole body $\dot{V}O_{2max}$ is smaller and the muscles are not sports specific. Horizontal running, roller skiing using fast roller-skis—especially on flat terrain—and road-cycling most probably do not develop whole body $\dot{V}O_{2max}$ and central oxygen transport of cross country skiers because neuromuscular and peripheral factors limit the attainment of high $\dot{V}O_2$ during training. However, neuromuscular characteristics, peripheral oxygen utilization and energy yield may be improved.

Intensity

The intensity of training should be as close to $\dot{V}O_{2max}$ as possible ($\dot{V}O_2$ 85–100% of $\dot{V}O_{2max}$), close to or higher than the intensity of maximal lactate steady state (~ BLaSs$_{max}$, ~ RCT, ~ 'anaerobic threshold'; see Chapter 1). The intensity of training is usually controlled by heart rate monitors. Heart rate should increase to values attained during ski-race, 90–100% of maximum heart rate (HR$_{max}$), 0–15 b.p.m. below individual HR$_{max}$. Recommended heart rate has usually been prescribed from field or laboratory measurements of blood lactate and heart rate during incremental treadmill exercise. Figure 3.5 shows the blood lactate–heart rate curve from the laboratory treadmill ski-striding measurements for the winner of several Olympic gold medals at the beginning (June) and at the end (October) of a summer training period. Based on the curves, prescribed heart rate for $\dot{V}O_{2max}$ training was 167–180 b.p.m. in June and 170–181 b.p.m. in October, a few b.p.m. lower than HR$_{max}$, 182 and 183 b.p.m., respectively. When the treadmill-determined heart rates are used as guidelines for $\dot{V}O_{2max}$ training, blood lactate usually increases to 4–10 mmol·l^{-1} during training.

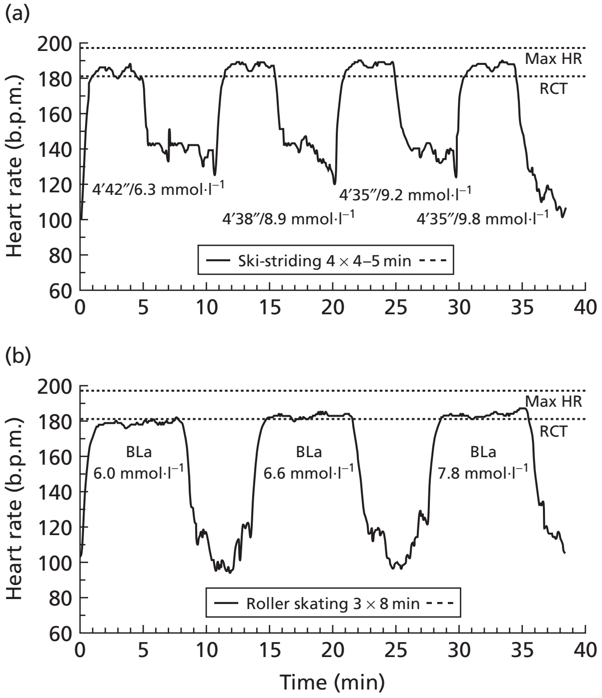


Fig. 3.6 Heart rate (*y*-axis) and blood lactate concentration (numbers below heart rate curve) during two interval-type uphill $\dot{V}O_{2max}$ training exercises. (a) 4 × 4.5 min uphill pole striding (performance times also given) and (b) 3 × 8 min uphill roller skating. National team female skier during summer training period in 2001. Maximal and RCT heart rates are also given.

$\dot{V}O_{2max}$ training is usually carried out as interval-type training, e.g. 3–5 × 4–8 min (Fig. 3.6). During $\dot{V}O_{2max}$ training lactic acid is produced in the active muscles and blood lactate starts to accumulate. Therefore, the exercise intensity has to be controlled carefully as a slight increase in training intensity/velocity increases the accumulation of blood lactate, induces fatigue and influences the performance velocity as well as the number of repetitions during interval-type training (Fig. 3.7).

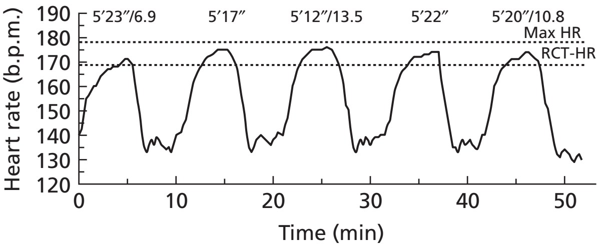


Fig. 3.7 Interval-type uphill $\dot{V}\text{O}_{2\max}$ training during skiing on snow. Heart rate curves during skiing and uphill skiing times are given as well as blood lactate concentration after the third and fifth performance (see text for further explanation). Male world champion skier. Maximal and RCT heart rates in a treadmill pole walking–striding test are also given.

Duration and frequency

The duration of exercise has to be long enough that $\dot{V}\text{O}_2$, stroke volume, heart rate, cardiac output and ventilation stay at the maximum or near maximum values for at least 15–30 min.

During fast distance training, the intensity of BLaSs$_{\max}$ (85–90% of $\dot{V}\text{O}_{2\max}$) can easily be maintained for 20–30 min and the 100% $\dot{V}\text{O}_{2\max}$ intensity for 3–6 min. During distance training in varying terrain (natural interval) $\dot{V}\text{O}_2$ and heart rate increases to or close to maximum in uphills, decreases in downhills, and can be maintained at 80–90% level of $\dot{V}\text{O}_{2\max}$ on average.

During interval training the optimal duration of exercise periods is 3–6 min with recovery periods of 2–5 min at lower intensity exercise, and the exercise periods are repeated 3–10 times. Shorter activity and interval periods may also be used but they are difficult to put into practice. The problem of short intervals is that, despite high heart rate and feelings of breathlessness, $\dot{V}\text{O}_{2\max}$ is not necessarily attained and the share of anaerobic energy yield may be high. However, close to racing season this kind of interval training is also to be recommended because the ski-tracks include uphills of different durations and during short interval training the velocity can be kept close to race velocity.

The example in Fig. 3.7 is from a typical interval-type uphill skiing $\dot{V}\text{O}_{2\max}$ training where the uphill skiing lasted for over 5 min and the intensity was over RCT ('anaerobic threshold') based on both heart rate and blood lactate. The velocity of the second and third uphill skiing bout were probably too high and blood lactate increased close to individual maximum. During the last two bouts, velocity decreased a little, heart rate was still a few b.p.m. above RCT heart rate and blood lactate was slightly decreased.

The frequency of $\dot{V}\text{O}_{2\max}$ training sessions varies considerably between skiers. However, experimental studies on young cross country skiers suggest that the individual upper limit for the frequency is 2–4 intensive training sessions per week (Fig. 3.8). Too

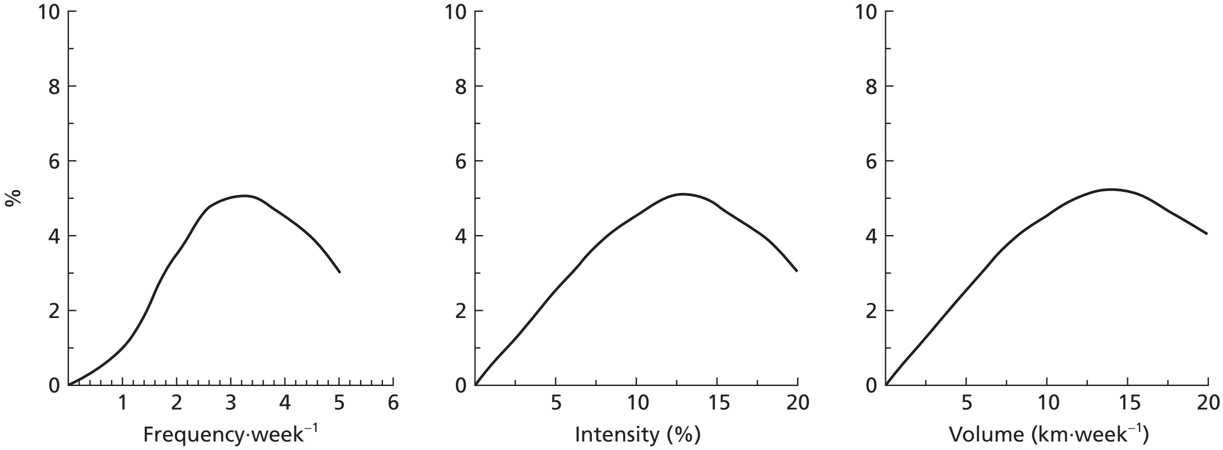


Fig. 3.8 The volume of intensive training influences the development of $\dot{V}\text{O}_{2\max}$. Based on studies on young 16–20-year-old female and male skiers, there seems to an upper limit to the optimal amount of weekly intensive training. Individual differences are high. (Modified from Kantola & Rusko 1985.)

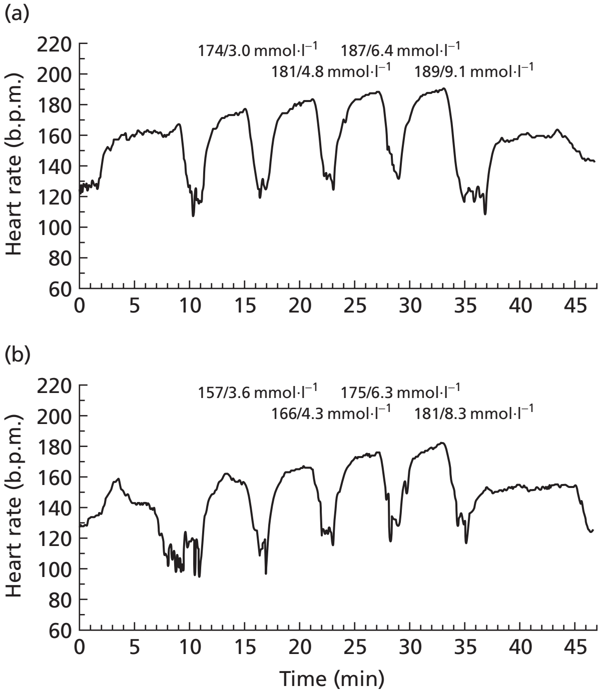


Fig. 3.9 Heart rate curves of a national-level skier during 4 × 4-min $\dot{V}O_{2max}$ training. (a) Whole body exercise (pole striding on treadmill) and (b) upper body exercise (double poling on an indoor track). Mean heart rate–blood lactate concentration after each exercise period is also given. Blood lactate concentration is often higher at the same heart rate during double poling than during training using legs and arms (see also Fig. 3.10).

high frequency or volume of intensive training leads to a smaller increase in $\dot{V}O_{2max}$, probably because of an imbalance between training stress and recovery (see Fig. 3.2 and Chapter 5).

Upper body $\dot{V}O_{2max}$ training

Training for upper body $\dot{V}O_{2max}$ is similar to that of the whole body $\dot{V}O_{2max}$ training. Training for upper body $\dot{V}O_{2max}$ requires that sport-specific muscles and movements be used, such as uphill double poling on snow, uphill roller skiing on road and double poling on a ski ergometer. Training heart rates should be separately prescribed for upper body training exercises because the blood lactate concentration at the same heart rate may be higher during double poling than during ski striding (Figs 3.9 and 3.10). Female skiers especially may have difficulties in attaining as high a heart rate during upper body $\dot{V}O_{2max}$ training as during whole body $\dot{V}O_{2max}$ training, probably because of small mass and low fatigue resistance of the upper body muscles.

Because upper body $\dot{V}O_{2max}$ is very much dependent on upper body muscle mass, strength training is an essential part of improving it (see section on Strength training). After periods of increasing muscle mass, periods for improving upper body $\dot{V}O_{2max}$, muscle oxidative capacity and blood flow of that increased muscle mass must be carried out. Studies on female skiers indicate that upper body strength and power training have improved upper body $\dot{V}O_{2max}$ as well as economy and race velocity of double poling; see also sections on ski-training on snow and training for neuromuscular endurance, this chapter; Muscle mass and upper body $\dot{V}O_{2peak}$, Chapter 1).

Improving fractional utilization of $\dot{V}O_{2max}$ and energy utilization

Interestingly, there are only minor differences in the LT, RCT and fractional utilization of $\dot{V}O_{2max}$ between

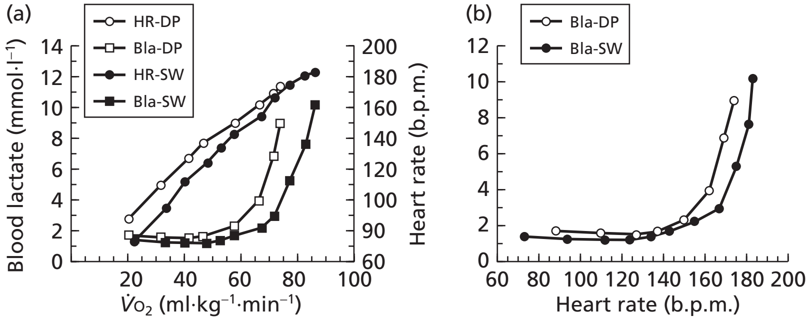


Fig. 3.10 (a) Blood lactate–$\dot{V}O_2$ and (b) blood lactate–heart rate curves of a world champion male skier during double poling on a ski ergometer and pole walking–striding on a treadmill indicate higher blood lactate accumulation during upper body exercise as compared to whole body exercise.

junior and elite adult endurance athletes, indicating that the most important factor in developing the velocity of prolonged exercise is the increase of $\dot{V}O_{2max}$. However, the fractional utilization of $\dot{V}O_{2max}$ can be improved and another important aspect is fatigue resistance; keeping up the same velocity and fractional utilization of $\dot{V}O_{2max}$ during the whole duration of a race. Elite adult athletes can sustain their slightly higher fractional utilization of $\dot{V}O_{2max}$ for a longer time than untrained or less trained athletes but it is not understood if this is related to energy utilization or to neuromuscular factors (see section on Neuromuscular fatigue resistance training). Oxygen transport cannot be the limiting factor of fractional utilization of $\dot{V}O_{2max}$.

Specificity, duration and intensity

From the energetic point of view, the training for improving fractional utilization of $\dot{V}O_{2max}$ should decrease blood lactate accumulation during training and racing, improve muscle glycogen sparing, and increase fat utilization. These adaptations occur in those muscles that are recruited during training, emphasizing the importance of using sport-specific muscles.

In the beginning of submaximal exercise, e.g. at the intensity of ~ $BLaSs_{max}$, muscle lactate production and concentration increase considerably while blood lactate concentration increases more slowly. After a few minutes, muscle lactate concentration starts to level off or to decrease because of the (facilitated) diffusion of lactate from muscles to blood when lactate concentration in the muscles increases. A balance between muscle and blood lactate concentration as well as between blood lactate accumulation and removal is attained in 5–10 min. Thereafter, blood lactate concentration stays at a relatively steady level or increases slowly during the exercise, depending on the intensity of exercise.

Blood lactate removal is a key factor. It increases with exercise intensity and is greatest at the intensity of $BLaSs_{max}$. Another factor that influences blood lactate removal is the blood lactate concentration: the higher the concentration the greater the elimination. This suggests that training for improving $BLaSs_{max}$ should include phases of increased lactate production and removal, as for instance during natural interval training.

Utilization of muscle glycogen stores decreases and utilization of fat for energy production increases the longer the duration of exercise. Muscle glycogen depletion studies suggest that FT fibres are increasingly recruited the longer the duration of exercise. It is believed that the oxidative capacity of the FT fibres as well as the overall ability to utilize fat is increased. High-intensity interval-type training (e.g. typical $\dot{V}O_{2max}$ training) can also increase oxidative capacity of FT fibres. Fat utilization is also increased during prolonged interval-type training compared to constant load exercise if the number of repetitions is high and the whole duration of training session is ~60 min.

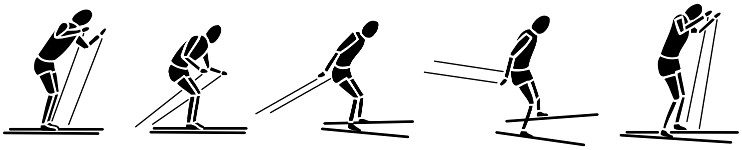
Typical exercises

In practice, two different distance training intensity zones have mainly been used to improve the fractional utilization of $\dot{V}O_{2max}$: low-intensity distance training at the intensity of ~ LT (volume or quantity training) and fast distance training at the intensity of ~ RCT or ~ $BLaSs_{max}$. During low-intensity distance training heart rate and oxygen uptake are 70–80% of $\dot{V}O_{2max}$. Table 3.1 shows average LT and RCT heart rates for adult and junior female and male skiers as well as the differences from maximal heart rate as guideline heart rates for low-intensity distance training and fast distance training. Heart rate tends to 'drift' up so that after 1 h exercise it may be 5–10 b.p.m. higher than during the first 10 min.

During low-intensity distance training blood lactate is always close to resting level even though it may slightly vary according to the terrain. The duration of exercise is 1–3 h or more and, because of the specificity principle, the training mode should recruit those muscles that are used during skiing. Because oxygen transport is not a limiting factor, the muscles in question can be more easily overloaded by the duration of training session to increase their oxidative capacity and fat utilization. Examples of training modes are running, cycling, roller skiing during summer dry-land training and prolonged skiing (diagonal, skating, and/or double poling technique) on snow in varying terrain during winter.

It is believed that distance training at low intensity does not improve $\dot{V}O_{2max}$ but, interestingly, during prolonged skiing lasting for more than ~2 h heart rate may start to decrease even though the velocity or

Table 3.1 Maximal heart rates (HR) and heart rates corresponding to respiratory compensation threshold (RCT) and lactate threshold (LT) for different groups of cross country skiers in a treadmill pole walking test (mean ± SD).



	Elite male	Elite female	Female	Junior female	Junior male
Max HR	188 ± 8	197 ± 9	205 ± 3	193 ± 7	199 ± 9
RCT	171 ± 10	179 ± 10	190 ± 1	172 ± 10	181 ± 11
LT	155 ± 11	165 ± 13	176 ± 5	146 ± 8	152 ± 13
Max-RCT	–17 ± 4	–17 ± 3	–15 ± 3	–21 ± 5	– 18± 5
Max-LT	–33 ± 5	–32 ± 5	–29 ± 5	–47 ± 7	– 47± 6

absolute exercise intensity is the same. The circulating stress hormones and, consequently, the contractility of heart muscle may be decreased and heart muscle is probably ‘forced’ to stretch more before contraction and thereby to increase the stroke volume (utilizing the so-called Frank–Starling mechanism). Therefore, low-intensity distance training may increase stroke volume, increase the potential for the development of high maximum cardiac output and enhance the development of so-called ‘athlete’s heart’. Fatigue resistance of the heart muscle is probably also improved. As an example, one world champion cross country skier attained his highest $\dot{V}O_{2max}$ ever (93 ml·kg^{-1}·min^{-1}) after a period of low-intensity November ski-training on snow.

Fast distance training at the intensity of $\text{BLaSs}_{\text{max}}$ is another typical training session for improving fractional utilization of $\dot{V}O_{2max}$. It has been regarded as the best training for improving the fractional utilization of $\dot{V}O_{2max}$ and fatigue resistance, especially by the former East German researchers and coaches. As shown above, there are good bases for supporting this opinion. Blood lactate concentration during training is individually 2–8 mmol·l^{-1} (0.5–6 mmol·l^{-1} over resting level), indicating high lactate turnover: lactate transport into blood equals the removal of lactate from blood. Heart rate and oxygen uptake are 80–90% of $\dot{V}O_{2max}$, meaning that this kind of training may also improve $\dot{V}O_{2max}$. Ventilation is high enough to improve the fatigue resistance of respiratory muscles. Training at this intensity is psychologically demanding and physically stressful (Table 3.2).

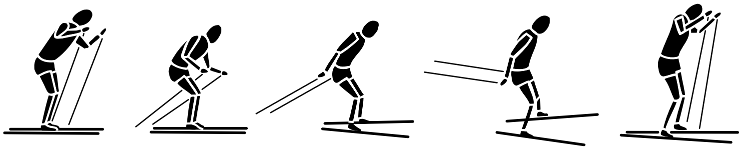
Interval training is also beneficial for improving fractional utilization of $\dot{V}O_{2max}$ and energetic fatigue resistance. Studies on cyclists indicate that interval training 5–9 times 5 min at 85–90% of $\dot{V}O_{2max}$ with 1 min recovery improved the fractional utilization of $\dot{V}O_{2max}$ and endurance performance. Studies on runners and untrained persons also confirm that different interval training combinations can improve fat utilization and oxidative capacity of FT fibres. The natural interval training of cross country skiers corresponds to this kind of interval training: in varying terrain $\dot{V}O_2$ increases to or close to maximum in uphills, decreases in downhills and flat sections, and can be maintained at 80–90% level of $\dot{V}O_{2max}$ on average (Fig. 3.11).

The training programme of elite cross country skiers usually includes both fast distance training and low-intensity distance training as well as natural interval training with intensity varying between LT and RCT. This kind of training constitutes 70–85% of the total training volume of cross country skiers.

Ski-training on snow

The principles of ski-training on snow are similar as those of dry-land training. A typical blood lactate–heart rate curve during ski-training on snow is seen in Fig. 3.12. The velocity window for different training zones seems to be small during ski-training on snow. According to the curve, the velocity window for $\dot{V}O_{2max}$ training is 2 min 58 s–3 min 5 s per kilometer, and for $\text{BLaSs}_{\text{max}}$ training it ranges between 3 min 5 s

Table 3.2 Heart rate (HR, b.p.m.), blood lactate concentration (BLa, mmol) and rated perceived exertion (RPE) of five male and five female endurance athletes (HR at RCT 173 and 175 b.p.m., respectively) during 3 × 20 min maximal lactate steady state training on a treadmill. Some male and some female athletes were exhausted before the end of the last 20-min period even though their blood lactate concentration was relatively low, while some could finish with high blood lactate concentration. RPE-rating 18–20 means 'very, very hard or extremely hard' suggesting central nervous system limitation.



Men				Women			
Time (min)	HR (b.p.m.)	Bla (mmol)	RPE	Time (min)	HR (b.p.m.)	Bla (mmol)	RPE
5	160			5	156		
20	175	3.6 ± 1.6	16.5 ± 1.7	20	174	3.9 ± 1.4	15.2 ± 0.4
25	165			25	165		
40	178	3.4 ± 1.2	17.3 ± 1.7	40	181	5.3 ± 2.4	17.8 ± 0.8
45	172			45	174		
57.5 ± 0.8	180	3.4 ± 0.8	18.3 ± 1.3	55.1 ± 0.9	185	5.3 ± 2.0	18.6 ± 1.1

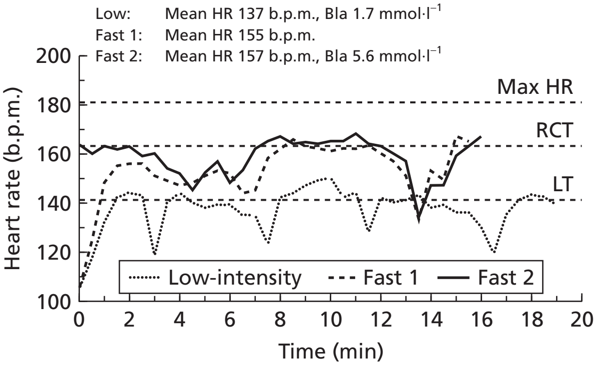


Fig. 3.11 Typical heart rate curves and blood lactate concentration during low-intensity distance training (first 5 km lap) and fast distance training (2 laps) on snow at the intensity corresponding to LT and RCT, respectively. Mean heart rates and blood lactate concentrations after the first and third lap are given. During downhills heart rate decreases considerably, especially during low-intensity distance training.

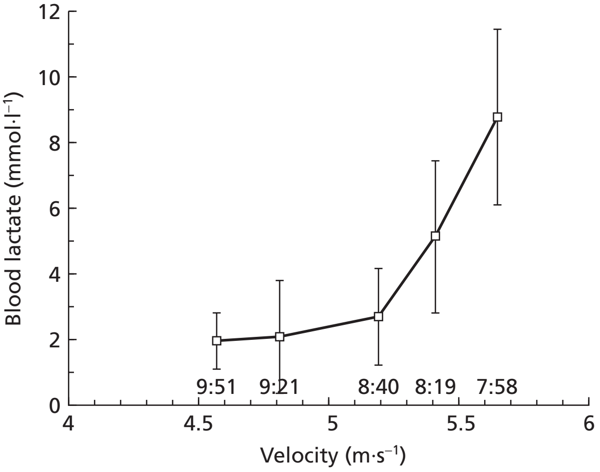


Fig. 3.12 Blood lactate concentration of seven national team male skiers after skiing a 2.7-km lap at five different velocities. Lap times in min: s are also given (see text for further explanation). (Modified from Kantola & Rusko 1985.)

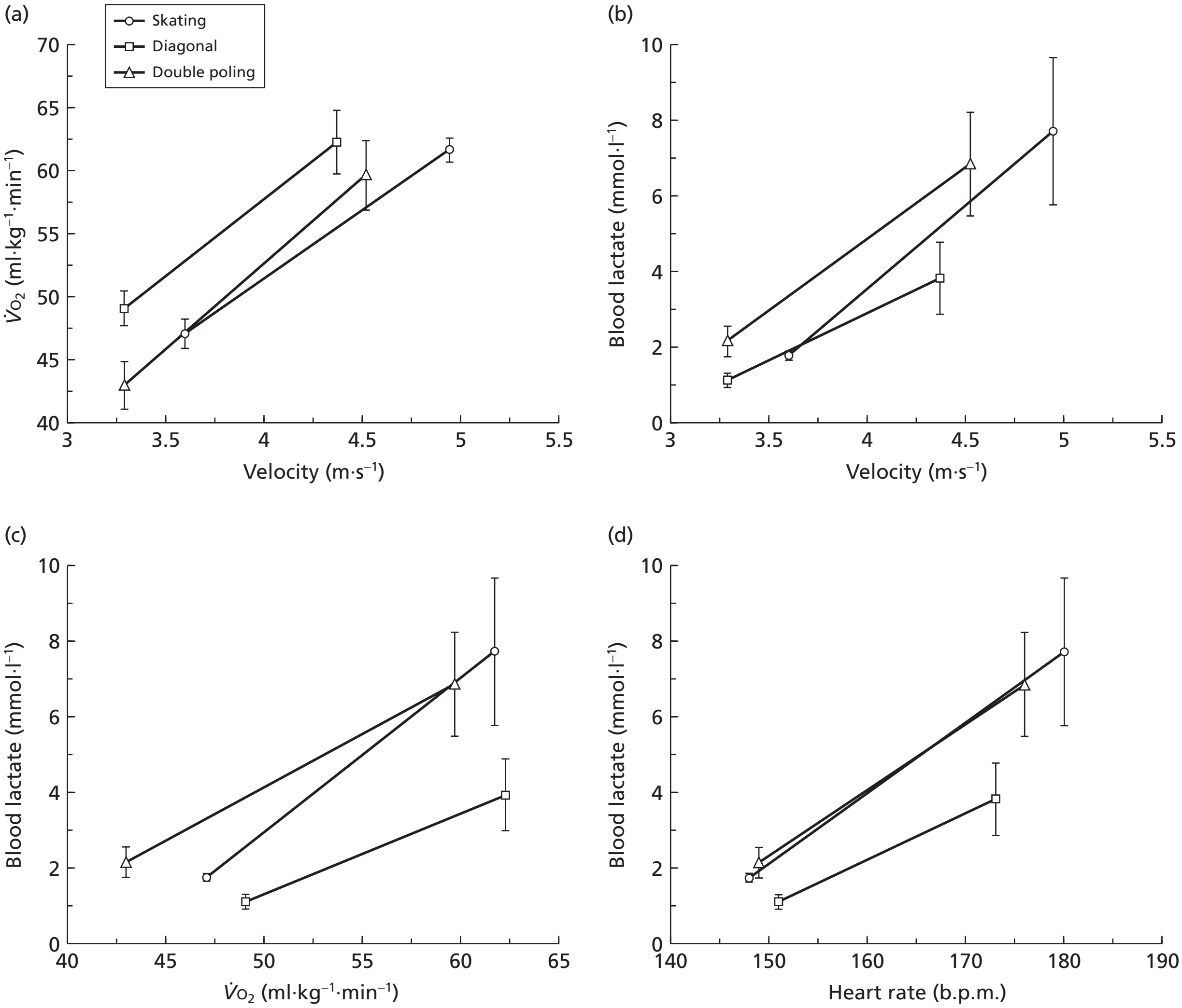


Fig. 3.13 Comparison of skating, diagonal skiing and double poling during gently sloping uphill skiing on snow at two different velocities corresponding approximately to LT and RCT. Diagonal skiing is least economical but blood lactate data indicate that diagonal skiing is superior for aerobic endurance training (mean ± SD).

and 3 min 12 s per kilometer. Weather conditions during ski-training influence the blood lactate accumulation and make it difficult to decide the training velocity. When the tracks are icy and slippery, blood lactate concentration increases more easily than during skiing in normal snow conditions.

During ski-training on snow the differences between classical and freestyle skiing and double poling have to be taken into account. During V2 ski-skating and during double poling (both on snow and during roller skiing) a great share of the work is done by the upper body muscles that may increase blood lactate accumulation. During skating, blood flow to leg muscles may also be limited because of isometric-type muscle contraction, especially in low skating position. Several studies have confirmed that blood lactate accumulation is greater during skating and double poling than during diagonal skiing at the same oxygen uptake and/or the same heart rate (Fig. 3.13). Female and junior skiers especially are prone to high blood lactate concentration during double poling and ski skating compared to diagonal skiing, probably because of the small muscle mass of upper body muscles. During dry-land training the differences between double poling and ski-walking also confirm the higher blood lactate accumulation during upper body training compared with whole body exercise at the same heart rate (Figs 3.9 and 3.10).

In Chapter 1 it was shown that the $\dot{V}O_{2max}$ of male skiers was lower during uphill skating on snow than during treadmill ski-walking with poles or during uphill diagonal skiing on snow (see Fig. 1.17). Female skiers attained a lower $\dot{V}O_{2max}$ during uphill ski-skating than during uphill diagonal skiing. These findings suggest that during the winter season it may be difficult to improve $\dot{V}O_{2max}$ using skating techniques as the only exercise mode and that $\dot{V}O_{2max}$ should also be trained using diagonal techniques. Upper body $\dot{V}O_{2max}$ should also be trained using double poling techniques during winter.

Main points to remember about training for aerobic endurance

- Whole body $\dot{V}O_{2max}$ training requires that great muscle mass is activated; optimal training modes are sport-specific uphill skiing on snow, uphill ski-walking and ski-striding with ski-poles and uphill roller skiing.
- $\dot{V}O_{2max}$ training is usually carried out as interval-type training with 3–6 min activity periods and 2–5 min recovery periods.
- Fast distance training at the intensity of 85–100% of $\dot{V}O_{2max}$ for 10–30 min and natural interval training are also good training exercises for improving $\dot{V}O_{2max}$.
- The intensity of $\dot{V}O_{2max}$ training can be controlled by heart rate monitors and occasionally by blood lactate measurements.
- Training for upper body $\dot{V}O_{2max}$ is similar to that of whole body $\dot{V}O_{2max}$ training but sport-specific movements and muscles are used, such as uphill double poling on snow and double pole roller skiing.
- Strength training is essential part of upper body $\dot{V}O_{2max}$ training to increase upper body muscle mass, but that period must be followed by periods of increasing the oxidative capacity and $\dot{V}O_{2peak}$ of the increased muscle mass.
- The training for improving fractional utilization of $\dot{V}O_{2max}$ includes fast distance training, low-intensity distance training and natural interval training with intensity varying between LT and RCT. This kind of training exercises form 70–85% of the total training volume of cross country skiers.
- Skiing-specific muscles must be used when training for improving fractional utilization of $\dot{V}O_{2max}$.
- During ski-training on snow the differences between diagonal and skating techniques and double poling with respect to blood lactate–heart rate and blood lactate–$\dot{V}O_2$ curves as well as to $\dot{V}O_{2max}$ have to be taken into account.

Training for neuromuscular endurance

During cross country skiing relatively small forces have to be produced quickly and repeatedly, hundreds or thousands of times. The forces used in cross country skiing have been described in Chapters 1 and 2. In summary, the forces used during cross country ski-race are 5–30% of the maximum isometric force and 20–50% of the maximum dynamic force of the corresponding muscles. Energy for repeated force production comes from aerobic and/or anaerobic energy sources and the forces have to be produced in a coordinated way, even when oxygen uptake and blood lactate concentration are high and the functional systems of the body are fatigued. Anaerobic energy for force production is yielded during uphill skiing, regardless of skiing techniques, because the energy demand exceeds $\dot{V}O_{2max}$ and the contraction phase of muscles relative to the relaxation phase (work : recovery ratio) increases. Anaerobic energy yield is also enhanced when the small muscles of upper body are activated during fast double poling and skating. During steep uphill skating the upper body muscles may produce 50% of the total force for forward movement and during double poling on flat and gently sloping uphill the upper body muscles may produce the total propulsive force.

Because the forces produced during cross country skiing are relatively small, most skiers have enough maximal strength but may not have the ability for fast force production. They may not be able to recruit a high enough proportion of their muscles/muscle fibres during skiing, and their force production may decline during the race as a result of too great anaerobic energy production and some other factors which impair neuromuscular function and decrease force production (see Chapter 1). This can be seen in the skiing velocity during ski-races. Almost all skiers have the same skiing velocity during the first 0.5–1.0 km, after which the differences between skiers start to increase indicating that the differences later in the race depend mainly on the ability to keep up the force production and skiing velocity (muscular endurance, fatigue resistance).

General strength and muscular endurance training

For cross country skiing the strength and muscular endurance of all muscle groups of the body are important, especially the arm, shoulder, back and abdominal muscles. After the skating technique was adopted the importance of the upper body and gluteus muscles has increased. Therefore, the skier has to carry out general muscle strength and muscular endurance training, e.g. general circuit training, in the beginning of his or her career and then slowly proceed to more sport-specific strength and muscular endurance training. Most skiers have enough muscle mass in those muscles that are used in cross country skiing; however, some female and junior skiers and a few male skiers may need to increase their maximal muscle strength and muscle mass, especially in their upper body.

Muscle mass can be increased by general maximal strength training using 70–90% force level of maximal strength; the maximal number of repetitions (repetition maximum, RM) before fatigue is 3–30 (= 3–30 RM). The increase in muscle mass is usually attained with 3–4 sets of 10–15 RM at relatively slow contraction velocity and 2–5 min intervals between sets. This kind of strength training is carried out 2–4 times per week for 6–10 weeks. During the first 3–4 weeks muscle strength increases mainly as a result of improved neural recruitment and thereafter mainly because of increase in muscle mass. Because of their different hormonal profile, female skiers may have difficulties in increasing their muscle mass and an improved neural recruitment is mainly responsible for the improvement in muscle strength. Strength training studies suggest that female skiers may benefit more from shorter strength training periods of 4–6 weeks that are repeated after a few weeks' recovery period. If a skier has enough muscle mass it might be more feasible to increase the recruitment of the muscles. For that purpose, maximal strength training using sets of 1–3 RM could temporarily be used. However, this kind of training is not common among cross country skiers. Maximal recruitment can also be improved by the above-mentioned general maximal strength training and by explosive-type strength training (see the next section).

Skiers with enough muscle mass and maximal muscle strength should emphasize muscular endurance training. The basic principles of muscular endurance training are as follows.

- Select training exercises that are as ski-specific as possible, especially as the ski-season approaches.
- Do as many repetitions as possible in a predetermined time, recover and repeat.
- Imitate the movement velocities of skiing as far as possible.
- Alternate muscle groups during a session to allow recovery between sets.
- Remember that more successful skiers have shorter force production phases during kick (legs) and push (arms) and longer glide phases than less successful skiers, and with increased velocity of skiing the forces have to be produced faster.

Typical muscular endurance training is a circuit training session with a high number of repetitions (15–100), low force level (30–60% of 1 RM) and moderate to high movement velocity (60–90% of max) corresponding to those of skiing performance. If the aerobic energy yield during muscular endurance training is emphasized, the number of repetitions could be 50–100s with force level and movement velocity slightly lower than above. Exercises that mimic skiing, e.g. skating on slide board, can be included in the exercises in circuit training. The 'aerobics' training is many-sided muscular endurance training that skiers could also include in their training programme.

Upper body and arm muscle strength, power and muscular endurance training increases muscle mass and recruitment of muscles and can simply be trained using different devices designed to simulate the movement pattern of the arms during double poling. Elite cross country skiers have commonly used roller board exercises with high number of repetitions, slightly higher force level compared to double poling and movement velocities close to those of skiing. At its simplest, improvement in upper body maximum force, power, muscular endurance and the economy of double poling has been attained by doing three sets of six repetitions with a load corresponding to 6 RM (about 85% of 1 RM), three times per week for 9 weeks (Table 3.3 and Fig. 3.14). Skiers also do muscular

Table 3.3 Time spent performing different training activities in the 9-week, three times per week maximal strength training study on female cross country skiers (Hoff *et al.* 1999).

	Strength group	Control group
Training volume ($h \cdot week^{-1}$)	8.5 ± 0.8	9.2 ± 1.2
Endurance		
Long distance (%)	59 ± 2.7	62 ± 2.7
Interval (%)	11 ± 2.7	10 ± 2.7
Strength total		
Muscular endurance (%)	2 ± 6.2	13 ± 1.0
Maximal strength (%)	7 ± 6.2	–
Other training (%)	21 ± 4.9	15 ± 4.8

Other training involves activities such as stretching, soccer and technique training. Exercise intensity of interval and long-distance training were performed at an intensity of 85–95 and 70–85% of HR_{max}, respectively.

endurance training with lower load and greater number of repetitions using these same devices. The movement velocity should then be close to double poling movement velocities.

The increase in muscle strength and muscle mass may be detrimental for endurance performance because force production becomes slower and the aerobic capacity of the increased muscle mass is low. Therefore, training periods for increasing muscle strength and muscle mass should be during the summer and autumn training periods and they must be followed by periods of explosive strength and sprint training and aerobic endurance training using the increased muscle mass. Canoeists can attain almost similar $\dot{V}O_{2max}$ in running (leg work) and in canoeing (upper body work) and cross country skiers might benefit from the basic and sport-specific strength training of canoeists.

During strength and muscular endurance training muscle length tends to shorten and fast force production tends to be impaired. Therefore, general strength and muscular endurance training (as well as aerobic endurance training) should always be started and finished with a proper warm-up and cool-down that includes stretching exercises for the arm, shoulder, trunk, pelvis and leg muscles.

Explosive-type strength, sprint and maximal skiing power training

To be able to ski faster skiers have to learn to activate their muscles to a greater extent and faster than before. This can be done with sports-specific explosive-type strength training and sprint training. Typical exercises in explosive-type strength training are jumping exercises which enhance the function of the stretch–shortening cycle (alternative jumps, bilateral countermovement jumps, drop jumps, hurdle jumps, one-legged jumps) with and/or without additional weight, leg press and knee extensor–flexor exercises with low loads but high or maximal movement velocity (several sets of 5–20 repetitions, in total 30–200 repetitions per exercise per training session). The load of exercises is 0–40% of 1 RM. It is important that the exercises are done with the purpose of recruiting the muscles to a greater extent and faster than before; e.g. in alternative and one-legged jumps longer jumps should be aimed for.

A combination of explosive-type and heavy resistance strength training, including various jumping exercises (see above) and specific sprint training exercises on roller skis with low loads and high velocities as well as dynamic squat lifts with barbells (70–90% of 1 RM), has also been used to improve the strength and power of skiing muscles, in addition to ordinary muscular endurance training. This kind of training for 6 weeks increased force production and explosive strength of leg muscles without decreasing the aerobic endurance characteristics of cross country skiers (Fig. 3.15).

Transfer of the improved activation and faster force production into running and skiing velocity on snow (maximal skiing power) is done using sprints at velocities between race pace and maximal velocity (5–10 × 20–100 m). In these sprints faster velocity, shorter contacts and longer step/glide lengths should be aimed for. Sprint durations of 10–30 s and 5–10 sets are recommended, with 1–2 min recovery between sprints and 3–5 min between sets (Fig. 3.16). An example would be three sets of 5 × 10 s with 1 min recovery between sprints and 5 min recovery between sets. Short sprints and long recovery times mean that blood lactate does not increase very much. Force or velocity can be varied using flat, gently or steeply

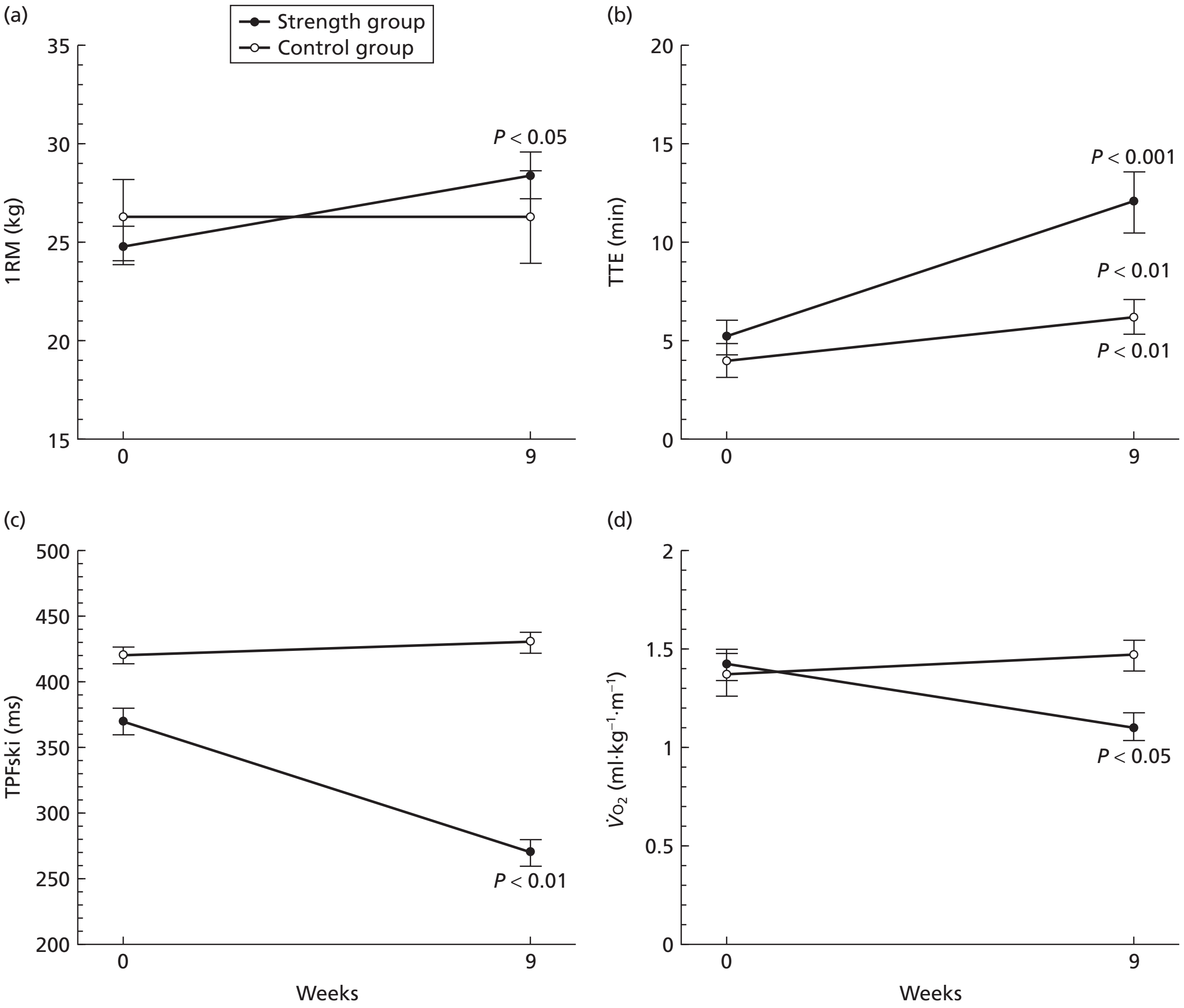


Fig. 3.14 Data on (a) upper body and arm muscle strength (1 RM); (b) time to exhaustion (TTE); (c) time to peak force (TPFski); and (d) economy ($\dot{V}O_2$) on double poling ergometer indicate that concurrent maximal strength and endurance training (see Table 3.2) improves double poling performance of cross country skiers. (Modified from Hoff *et al*. 1999.)

sloping uphill sections and gently sloping downhill sections as well as different skiing techniques. When 10–30-s sprints are added to low-intensity distance training, the volume of sprint skiing at maximal velocity or at race pace can easily be increased (see Fig. 3.16 and section From techniques to economy). Short maximum velocity races and longer time trials using different skiing techniques can also be used, when blood lactate accumulation is high and fatigue resistance is also improved.

The goal is to increase maximal skiing velocity and maximal (anaerobic) skiing power. The training period for improving these characteristics is 3–9 weeks and requires that demanding explosive-type strength and sprint training is done 2–4 times per week.

Neuromuscular fatigue resistance training

During race performance, lactate is produced in the ski-specific muscles, oxygen saturation of blood may

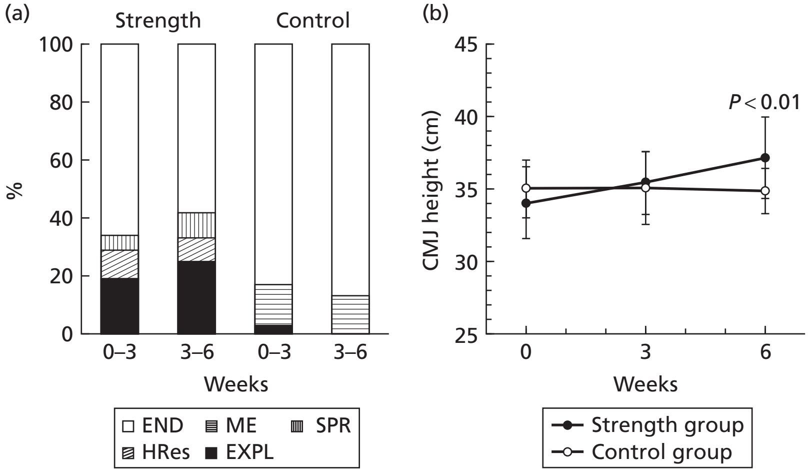


Fig. 3.15 (a) The relative volumes of the different training modes in the strength training and control groups of cross coutry skiers during a 6-week training period. (b) The changes in the mean ± SEM of countermovement jump (CMJ) height during a 6-week training period. END, endurance; EXPL, explosive strength; HRes, heavy resistance; ME, muscular endurance; SPR, sprint. (Paavolainen *et al.* 1991.)

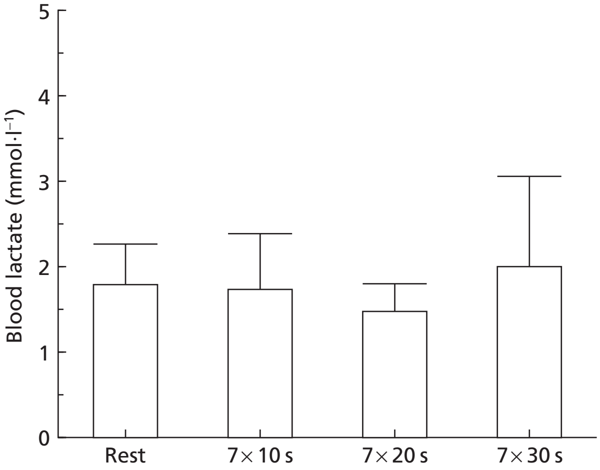


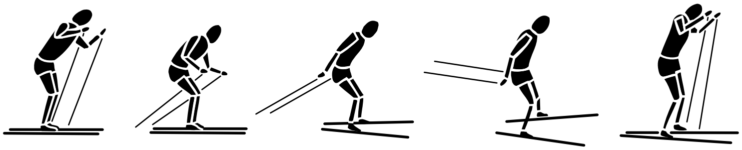
Fig. 3.16 Blood lactate concentration after 7 × 10-s, 7 × 20-s, or 7 × 30-s sprint skiing at race pace. Interval duration between sprints was 2–4 min at low-intensity distance training velocity. Mean ± SD for eight national team male and female skiers. The 7 × 30-s sprints increased blood lactate concentration of two female skiers slightly above 3 mmol·l^{-1}.

be decreased, respiratory muscles may produce lactate and become fatigued and muscle glycogen stores may be depleted. This information is processed in the CNS and, as indicated in Chapter 1, the decreased endurance performance may also be caused by neuromuscular fatigue.

Based on the information obtained from world-class cross country skiers, the fatigue resistance of the body (and of the CNS) can be improved by increasing the cruising velocity of distance training and especially the velocity of fast distance training as close to the race pace as possible. This is also good for improving skiing economy at race pace. The optimal duration of a training session is 30–60 min at high velocity, ~ $BlaSs_{max}$, and athletes usually feel tired at the end of the training session regardless of low blood lactate level. Data in Table 3.2 show that during constant load submaximal treadmill exercise at the intensity of $BlaSs_{max}$ some endurance athletes were exhausted within 1 h, even though their blood lactate concentration was low, oxygen transport was not a limiting factor and muscle glycogen stores could not be depleted.

Feedback from muscles influences the perception of effort in the CNS and therefore the training modes should be ski-specific: diagonal skiing, skating and double poling during the on-snow season, as well as ski-striding, ski-bounding using ski poles and roller-skiing during the dry-land season. One practical approach to improve fatigue resistance is that two skiers train together so that skier 1 first leads and skier 2 pursues him or her; then the skiers change place, skier 2 leads and skier 1 pursues. Time trials and training at race pace have also been used. Another way to improve neuromuscular fatigue resistance is a 3–4-week training period using a weight vest during

Table 3.4 Added load training using a 2–4 kg weight vest during 3–4 training sessions per week for 3.5 months did not improve endurance characteristics of biathlon skiers. However, half of the experimental added-load skiers indicated overtraining symptoms (increased heart rate difference between supine and standing positions in the orthostatic test) while half showed an unchanged heart rate response (AL/OHR) and improved performance characteristics.



	Added load ($n = 7$)		Control group ($n = 7$)		AL/OHR < 15 ($n = 3$)	
	Before	After	Before	After	Before	After
$\dot{V}O_{2max}$	66.7 ± 3.1	68.7 ± 3.4	71.0 ± 2.9	73.1 ± 3.0*	66.7 ± 2.9	69.7 ± 2.8*
RCT	52.6 ± 3.0	52.0 ± 3.1	54.4 ± 2.9	57.0 ± 2.9*	51.7 ± 3.0	55.0 ± 2.8
LT	39.0 ± 2.0	41.1 ± 2.3	42.4 ± 1.7	43.6 ± 1.8	40.0 ± 2	44.3 ± 1.6*
HR-diff.	15 ± 6	15 ± 7	9 ± 4	18 ± 9	9 ± 4	9 ± 4

* Significant change, $P < 0.05$.

some sport-specific endurance exercises; e.g. during 2–4 different training sessions per week at different intensities (slow distance training, fast distance training, $\dot{V}O_{2max}$ training) a weight vest of 2–5 kg (depending on sex and body mass) is used. One session using a weight vest could be a sport-specific strength training session or circuit strength training session (Table 3.4).

The function and fatigue resistance of the stretch–shortening cycle is an important aspect. In addition to jumping, bounding and striding exercises, prolonged dry-land bounding and striding exercises using ski poles are recommended in circuit training. The number of 'jumps' or strides over a certain distance (e.g. 100–500 m) can be counted and in the next workout a smaller number of jumps or strides is aimed for.

The period for improving fatigue resistance is 2–4 training sessions per week for 2–4 weeks. Fatigue resistance training is very demanding and exhausting and it must be supplemented with low-intensity distance training without any requirements on the CNS or on anaerobic energy production. To decrease the risk of overtraining, recovery measures must be enhanced (Table 3.4).

Simultaneous training for strength and endurance

Cross country skiers and especially sprint race skiers have to do strength training and endurance training concurrently and they should be able to improve both aerobic power and neuromuscular characteristics. Studies on cross country skiers and other endurance athletes show that either general maximal strength training or explosive-type strength and sprint training carried out concurrently with endurance training has improved maximal force, explosive force production, sprinting velocity, 5-jump distance, countermovement jump (CMJ) height, maximal anaerobic muscle power, maximal double poling power, fatigue resistance (time to exhaustion during double poling), shortened contact time during 5 km running time trial and/or improved the economy of running and double poling (Figs 3.14 and 3.15). In those studies the duration of the enhanced strength training was 6–9 weeks and the frequency of training was 2–4 times per week. However, the longer the strength training period the greater the risk of decreased $\dot{V}O_{2max}$ and related endurance characteristics.

From the point of view of sprint skiing, an interesting finding has been that the percentage of strength training has been up to 30–40% of total training volume (Fig. 3.15), and that has not decreased (or increased) whole body $\dot{V}O_{2max}$. Simultaneous endurance and upper body strength and power training has also improved double poling performance (Fig. 3.14).

In distance runners the 5-km time trial has also improved after simultaneous explosive strength and endurance training and the improvement in running performance was related to the improvement in neuromuscular muscle power factors. Total training volumes of the strength and control groups were similar, but the percentage of explosive strength training were 27–34% and 3–5% respectively. $\dot{V}O_{2max}$ changes in the strength group were not significant but tended to decrease after the sixth week. Instead, the economy of performance ($\dot{V}O_{2submax}$) and performance in the $\dot{V}O_{2max}$ test ($\dot{V}O_{2maxdemand}$) improved in the strength group. The maximal 20-m sprinting velocity (V_{max}) and maximal anaerobic running velocity (V_{MART}) improved also in the strength group.

The order of strength and endurance training sessions seems to be of minor importance. However, it may be feasible to have the strength training session before endurance training on the same day. Also, when a skier has a strength training period he or she should only keep up his or her endurance characteristics and vice versa.

The effect of concurrent 'neuromuscular' and endurance training has also been studied during the November ski-training period on snow when the total volume of ski-training is high (Table 3.5). During this period the purpose was not to increase muscle strength but to prevent the decrease in the force–velocity characteristics of muscles and to improve the recovery of muscles. National ski team and junior ski team members were divided into two groups: control group and so-called quality group. The control group trained their high volume ski-training on snow as normal. The total training volumes of the groups were the same (mean 17.1 and 17.5 h per week) except that the quality group stopped some of their low-intensity distance ski-training sessions 30–60 min earlier than the control group and did dry-land exercises during that time (mean 3.9 vs. 1.7 h per week in the control group). The dry-land training included circuit and strength training, running, walking in soft snow, short running sprints, jumps, gymnastics and stretching.

Table 3.5 Changes in treadmill performance during experimental November training period for the quality and control groups who were members of national ski teams (see text for more information) (mean ± SD). In November the amount of ski-training on snow is usually high but performance capacity does not improve (control group, $n = 17$). 'Quality training' ($n = 8$) in November with emphasis on dry-land training exercises seems to guarantee a better development of performance capacity in national team adult and junior skiers. (Modified from Rusko *et al.* 1997.)

		Control	Quality
$\dot{V}O_{2max}$	Pre	75.6 ± 3.8	77.2 ± 2.3
($ml \cdot kg^{-1} \cdot min^{-1}$)	Post	75.4 ± 3.9	78.4 ± 2.6*
$\dot{V}O_{2maxdemand}$	Pre	79.4 ± 3.5	80.7 ± 1.9
($ml \cdot kg^{-1} \cdot min^{-1}$)	Post	80.4 ± 3.9	83.6 ± 1.9**
RCT	Pre	58.9 ± 3.6	59.9 ± 3.2
($ml \cdot kg^{-1} \cdot min^{-1}$)	Post	58.7 ± 4.0	61.6 ± 1.9*
CMJ	Pre	42.3 ± 4.0	41.2 ± 3.2
(cm)	Post	41.5 ± 3.7	42.4 ± 3.5*

*$P < 0.05$; **$P < 0.01$.

After the November volume training period the $\dot{V}O_{2max}$ and performance in the $\dot{V}O_{2max}$ test ($\dot{V}O_{2maxdemand}$) as well as RCT and CMJ height had increased significantly in the quality group ($n = 8$) while in the control group ($n = 17$) $\dot{V}O_{2max}$ and all other performance characteristics were unchanged (Table 3.5).

Main points to remember about neuromuscular endurance

- General strength training is done during junior years and, if necessary to increase muscle mass, during the summer training period.
- Because most skiers have enough muscle strength and muscle mass, skiers should emphasize sport-specific explosive-type strength, sprint and muscular endurance training.
- Mainly those muscles and muscle groups which are used during skiing must be trained, and the force levels, movement velocities and joint angles of exercises should correspond with those of skiing.

- Improved strength has to be transferred into better skiing velocity by using sprint and power training and into better fatigue resistance by increasing the velocity of distance training and by doing longer fast distance training sessions, time trials and using additional load during different training exercises.
- Concurrent strength and endurance training period can be used to improve force–velocity characteristics and fatigue resistance without decreasing aerobic performance characteristics.
- Young and less experienced skiers can start with a 3–4-week period of enhanced strength training, when 30% of training volume, 2–3 training sessions per week, is explosive-type strength and sprint training.
- More experienced skiers may need 3–6-week periods when 30–40% of training volume is explosive strength and sprint training. Longer periods may lead to a decrease in aerobic endurance characteristics.

Training for improving skiing techniques and economy at race pace

Cross country skiing performance can be reduced to relatively simple mechanical characteristics, which have been described in Chapter 2. The best ski competitors have physiological capacities (e.g. high fatigue resistance) and technical capabilities that allow them to ski at sustained speeds greater than those of other racers. Skiing speed derives from stride length and stride frequency. Fast skiers are generally no different to others in stride frequency but they are able to stride with greater displacement during each movement cycle. Increasing stride/glide length to ski faster through physiological and technical training is a simple objective which can be understood by young and more experienced skiers alike. Accomplishing that objective requires training of physiological responses, increasing strength and power (see previous sections), and development of ski technique which optimizes skiing speed for a given skier's capabilities. This section deals with technique training aimed at helping skiers develop movement patterns that enhance stride length and increase skiing speed.

Basis for technique training

Skiing at constant speed requires generating propulsive force in opposition to the drag forces acting against a skier's motion. To ski faster, either the propulsive forces must increase or the drag forces must decrease. Technique training is aimed at adjustment to both aspects of this force equilibrium. While in principle this is a clear objective, in reality training practices aimed at optimizing technique are based largely on conjecture because of the difficulty of actually measuring propulsive force and drag force during skiing. If one had access to full motion and force analysis instrumentation, technique training could be structured to directly manipulate force generation as a function of technique adjustments but such access is very rare worldwide and most skiers train without the benefit of full motion or force measurement and analysis. Particularly for young skiers, intuition and experience of coaches will generally be the basis upon which training plans are built rather than force and motion measurement. Given that reality, the technique training suggestions included in this section are readily implemented without extensive instrumentation.

Technique vs. individual style

While there are fundamental aspects that characterize each of the numerous cross country skiing techniques, some variability can be observed within a technique even for elite skiers. Such differences are caused by physical anatomy and strength variations in the population as well as learned idiosyncrasies that creep into an athlete's movement pattern. One of the challenges in coaching technique is to distinguish the small individual traits which have little influence on performance from those that have greater effect and which can be trained toward improved performance. A key concept in making this distinction is whether the movement trait might affect either propulsive force or drag force. If so, it is likely to be a characteristic to which both skier and coach should focus some attention.

Mechanical factors affecting propulsive force

In skiing, propulsive forces are generated either from upper body or trunk sources through the poles or from trunk or leg sources through the skis. In either case, the reaction forces applied by snow to the poles or the skis are three-dimensional vectors which have only a portion of the resultant force directed in the forward direction creating propulsion. The direction of the resultant force is a key concept with which to judge aspects of a skier's technique. For example, poling forces are not very effective in generating propulsion until the pole angle moves away from a relatively vertical position at pole plant. Hence, large forces early in poling do little to propel a skier forward. In diagonal stride, a skier's kick has both vertical and propulsive force components. The magnitude of the propulsive force interacts with the vertical force and with wax frictional force. The greater the vertical force, the greater the static friction of the ski gripping the snow, and the greater the propulsive force can be without ski slippage. Training should be aimed toward understanding these interactive relationships and implementing them in a skier's technical movement.

Mechanical factors affecting glide

Snow drag force is a complex factor acting to reduce glide of a ski during each stride. Waxing and ski preparation are important components in a skier's quest for better performance but are not dealt with in this handbook; however, ski positioning and skier-generated forces applied to a ski are factors that affect how well a ski glides with each stride. Technique adjustments, which reduce snow drag force, must be balanced against any simultaneous decrement in propulsive force that might be associated with such adjustment. For example, ski edging angle affects the pressure distribution under a ski, the amount of penetration into the surface snow and the drag acting against ski glide. If ski flatness is exaggerated in initial phases of a skating stroke, the ski is likely to glide with less drag force than if it were edged. However, when a skating ski is flat to the snow, propulsive force cannot be generated. Thus, while perhaps improving glide, such an emphasis on ski flatness might diminish propulsive force during a stride. It is the equilibrium between both drag and propulsive force which determines average skiing speed, so the overall effect for ski performance may not be positive from such an emphasis on ski flatness. Optimal technique will not overemphasize one aspect of technique to the detriment of other aspects (Fig. 3.17).

Fig. 3.17 Imitation of skilled performance may be more useful than repeatedly pointing out skier's own errors. 4 × 10 km relay in Nagano 1998, Björn Daehlie from Norway leading the race. Photo © Allsport/Al Bello.

Helping improve skiing skill

Optimizing the generation of propulsive force to balance against drag forces involves highly developed skill requiring motor learning through various pathways. While it is helpful for skiers (and coaches) to understand the underlying physical concepts explaining the effectiveness of aspects of technique, much motor learning is best acquired through other means.

Imitation of skilled performance vs. playback of own errors

Complex coordination and timing of the whole body that is required in skiing is not easily adjusted piece by piece but may demand absorbing the entirety of the movement and timing. This is perhaps best accomplished through visualization of highly skilled skiers either directly or on video. Simply skiing behind a skilled skier can be helpful to imprint an image of the timing and body positioning which one can learn to imitate. Such on-snow learning is particularly effective with young skiers who are absorbing the fundamentals of technique and building their mental images of particular movement patterns (memory engrams). Off-snow visualization can also be an effective means of establishing the timing and positioning images that are internalized as skilled technique is learned. Video examples from World Cup ski-races are widely available and may provide not only excellent illustrations of technique but also help stimulate enthusiasm for off-season training.

Small camcorders are often available to coaches and parents of young skiers. Recording of the skier's own technique and playback analysis can be useful to allow a skier to see particular technique errors. When combined with similar illustrations of highly skilled technique, the comparison can be instructive and help a skier to recognize extraneous movements or improper alignments that do not contribute to propulsion. However, there are potentially negative aspects to such viewing. One does not want to reinforce improper technique by strengthening the internal image associated with it; better is to reinforce the image of highly skilled technique with video illustrations and skiing with skilled companions than to repeatedly point out errors in a skier's technique. Recently, computer programmes have been developed for simultaneous playback of two different performances, e.g. a skilled performance and a young skier's own performance.

Dry-land training

During the dry-land season, some technique training can be particularly effective. Poling has long been incorporated by skiers into hiking and running activities which are primarily viewed as aerobic workouts. Poling technique can be improved in the process by careful attention to arm positioning from pole plant to full extension of the arm. Without requiring the attention to skis and balance that complicates on-snow training, one can better focus on correcting technical errors in poling. Both walking and running involve stride frequencies different from diagonal stride on snow. This does present a difficulty for dry-land poling sessions as the full poling motion requires more time and greater displacement than a typical walking or running step. Ski-bounding and striding have an exaggerated step length compared to walking or running and are used to train a longer/vigorous kick but have the advantage of more closely matching on-snow timing for proper poling. Alternatively, skipping instead of running changes the leg timing and adds displacement with each step so that poling more closely matches the movement pattern on snow. Running, skipping, striding or bounding with poles on forest trails can help skiers stay in tune with the rhythms of natural terrain, increase stride length and provide opportunity for both physiological and technique training at the same time.

Isolating technique components

An advantage of dry-land training is the ability to focus on an isolated part of ski technique such as poling without being distracted by other components of the full movement pattern. On snow, this approach can be used for some aspects of technique as well. For example, straight double poling with skis in set tracks can be helpful training for the faster skating techniques such as V2 or Open Field skating where the poling action is similar. Experimentation with pole plant angle, amount of extension at the end of poling, amount of trunk flexion and frequency can be included to find individual optima for this simpler technique with some carryover to the more complex skating techniques.

Leg movement patterns for diagonal stride and skating are perhaps best trained independently of poling. Skiing without poles is advantageous for improving weight transfer side-to-side in both skating and striding and is commonly used by elite skiers as well as by instructors in ski classes. While uphills become more challenging to ski without poles, it is instructive to include varying terrain in a no poles training route to allow focus on ski contributions to propulsion uphill and to realize how substantially poling aids uphill skiing.

Focus on single techniques can also be instructive for skiers. While varying terrain of ski trails is typically skied with smoothly changing techniques on flat, uphill and downhill, continuing a single technique across all terrain can provide a learning situation that shows a skier the potential shortcomings of any given technique. The varying terrain with a single technique forces the skier to adapt factors such as tempo, pole angles and amount of shoulder extension in poling. Within a given technique, it is also helpful to focus on parts of the whole for a period of time. For example, a training session in V1 skating might be skied in rolling terrain with 5 or 10 min spent paying attention to the weak side skate stroke, then attention to the strong side stroke, then each poling side, and so forth. With each focus, the ideal image can be kept in mind and the skier's movement refined to better approximate highly skilled technique.

Simple measurements to improve performance

While an ideal capability for technique training might include three-dimensional motion analysis and force measurement not possible for most skiers, many simple measurements can be made that do not require sophisticated instrumentation and yet provide valuable feedback about technique characteristics and effectiveness.

Time trials. Short sections of track of flat uniform uphill or varying terrain can provide a useful laboratory for experimenting with technique. Covering 1 or 2 km, ski the track repeatedly at race pace using one technique at a time. For example, compare skating times for V1, V2 and Open Field skating techniques on slight uphill terrain. This will give individual insight into race technique choice on similar terrain. If a heart rate monitor is available, the skier can check that heart rates are similar for each technique while using the timing to compare effectiveness.

Technique and fatigue. Near the end of a race fatigue may shift the relative effectiveness of some techniques, particularly for young skiers with limited fatigue resistance and upper body muscular endurance. Time trials as described above when skied at the end of long training sessions may indicate different technique choices to be more effective when fatigued at the end of races compared to when fresh early in a race. This also gives information on neuromuscular fatigue resistance.

Constant intensity skiing with varied technique. An alternative manner for comparing relative speeds of various techniques is to have a coach or someone else with a heart rate monitor ski in front while maintaining constant intensity (constant heart rate) near race pace. The skier behind can follow while systematically changing from one technique to another. Mental note should be made of which techniques seem to increase the physical demands and which seem easier. These will be subtle differences but may be detectable by heart rate response as well as perception. The comparisons will indicate a skier's technique weaknesses, may suggest where some additional training focus might be placed and how technique shifts in racing might be used to advantage.

Stride length comparisons within a group. A consistent finding about race performance is that the fastest skiers maintain longer stride (glide) length than do slower skiers while stride frequencies are similar. Within a training group, tracking of stride length for a given technique can provide useful comparison data for a skier. This can most easily be determined by measuring a straight portion of track between two fixed landmarks. A length of 100 m or so is sufficient to minimize measurement error for reliable assessment. For the stride length measurement two stopwatches are helpful. Ski through the zone at race pace while timing the passage. At the same time, with the second stopwatch time five or more complete strides within the zone. Use a 'flying start' for this test; in other words, be up to race pace before entering and maintain uniform pacing throughout the measurement zone. Example calculations for a 100-m length where a skier V2 skated through the zone in 20 s and had a five-stride time of 10 s: the skier's average speed was 5 $m{\cdot}s^{-1}$ (100 m in 20 s). The skier's stride frequency was 0.5 $strides{\cdot}s^{-1}$ (five strides divided by 10 s). Average stride length was 10 m (stride length is calculated from speed divided by frequency: 5 $m{\cdot}s^{-1}$ divided by 0.5 $strides{\cdot}s^{-1}$) (Fig. 3.18).

Stride length, frequency and speed data for a test zone can be maintained throughout a season for a whole group. While the data will vary as ski conditions change, the relative rankings within the group will be indicative of training breakthroughs for individual skiers which may improve their race performances. Body height differences have to be taken into account if comparing skiers with each other.

The predetermined distance can also be skied at 3–4 different velocities from slow to race and maximum velocity. The stride length, frequency and speed data for a test zone are calculated and stride length and frequency are drawn against velocity. These curves can be used to evaluate the development of stride length and skiing techniques at different velocities and comparisons between skiers can also

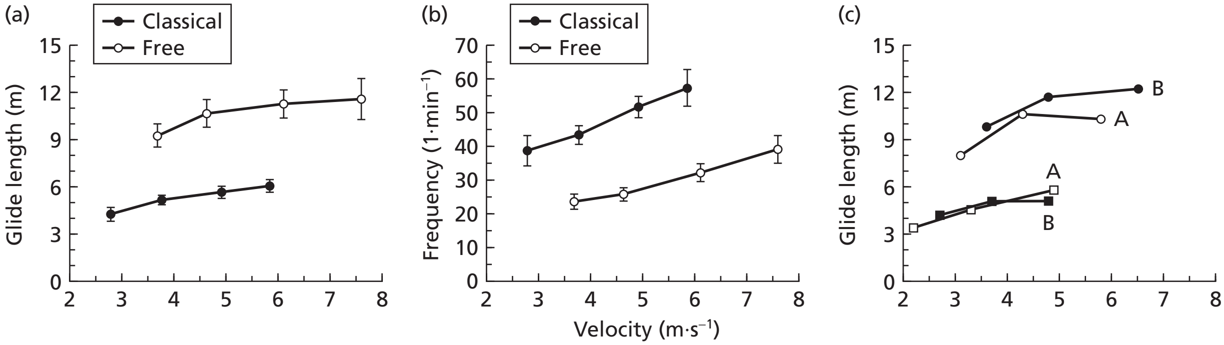


Fig. 3.18 Stride length and stride frequency at LT velocity, RCT velocity, at race pace and at maximal velocity on an 85-m gently sloping (5%) uphill section. (a, b) Means ± SD for eight junior male skiers having $\dot{V}O_{2max}$ of 78 ± 2 ml·kg^{-1}·min^{-1}. (c) Two skiers A and B, who had levelling off of glide length either during skating (A) or diagonal technique (B) skiing at race pace suggesting technique or neuromuscular limitation. Measurements were taken in the ski tunnel of Vuokatti Sports Institute, Finland. (Hynynen & Rusko, unpublished data.)

be made. Maximum velocity *per se* is also a good indicator of ski technique and velocity reserve (Fig. 3.18).

Video record of technique changes. Short video camera clips documenting the main ski techniques for a skier every month or so through the ski season can provide a useful record of technical improvements. In conjunction with a training logbook, such video records can help a skier and coach plan subsequent long range plans for technique training. While this is a useful approach, the main emphasis for video as a tool should remain a means of providing images of highly skilled technique rather than as a medium for criticizing errors. Positive image enhancement rather than negative movement pattern critique is probably a more effective coaching strategy.

Video record with laser radar velocity measurement. There are also new technical possibilities which can be used to give feedback to skiers, e.g. laser radar and related analysis programmes can be used to measure the velocity and velocity changes during the skiing cycle. This allows comparison of skiers and can also be used to compare different skiing techniques (Fig. 3.19).

Coaching guidelines—caution with generalizations

The complexity of skiing and difficulty of internalizing a highly skilled movement pattern often leads to simplification into pieces of the whole. This may ignore interactions amongst the component parts of a technique which collectively determine performance. In ski coaching, this may often appear in the form of brief phrases or suggestions which are intended to capture an essential component of a technique for easy remembering and action by a skier. Two examples of this approach are shown below. Both suffer from oversimplifying skiing technique and are potentially disadvantageous to performance.

'In skating, push from the heel' is a suggestion that coaches have been using to guide young skiers since the skating revolution in the mid-1980s. Its origins come from speed skating, which had much to teach ski skaters in the early years. On speed skates prior to the invention of the klap skate, it was essential to minimize plantar flexion at the ankle which tended to dig the tip of the skate blade into the ice, increasing frictional force. A focus on pushing from the heel was physically appropriate on speed skates. Unfortunately, that advice applied directly to ski-skating was not adequately tested for validity. Unlike traditional speed skates, ski-skating boots are not rigidly attached to the ski at the heel and have always allowed motion similar to the modern klap skate. A natural component of human walking, running and jumping is plantar flexion of the ankle near the end of foot contact with the ground. This has anatomical/physiological advantages involving the stretch–shortening cycle of the calf muscle. Elite skiers often

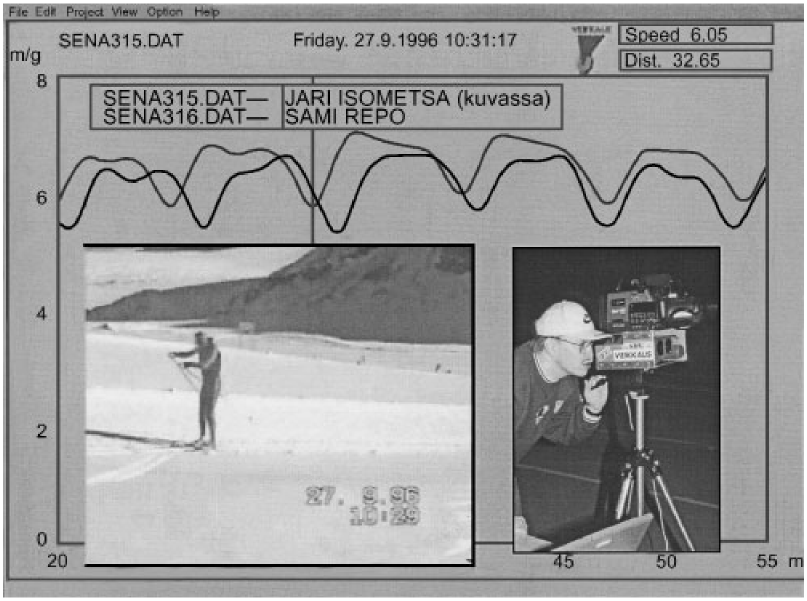


Fig. 3.19 Laser radar measurement of skiing velocity changes during consecutive skiing cycles and comparison between skiers can be made for improving the feedback to skiers. (Courtesy of Jukka Viitasalo, KIHU Research Institute for Olympic Sports, Jyväskylä, Finland.)

exhibit some amount of plantar flexion with the heel of the boot well off of the ski surface near the end of a skating stroke. Simplifying to a single phrase, 'push from the heel' does help skiers eliminate pushing backward (stepping forward) from the skating ski which is ineffective in generating propulsive force and kills the ski's glide. But, in oversimplifying, such phrasing fails to use to advantage the built-in human mechanisms for enhancing force generation and energy conservation and which contribute to faster skiing.

'Toe–knee–nose alignment in the skating stroke' is another guideline that has been used by coaches to help skiers position the body in skating and enhance weight shift from side to side. The intention was to provide a quick checkpoint that allowed a skier to visually see during each skating stroke whether the trunk had been sufficiently shifted over the skating ski. Unfortunately, if one analyses body positioning of highly skilled skiers, they do not align toe–knee–nose. The alignment from toe and knee is between the head and shoulder on the skating side—well away from the nose reference point. Trunk positioning so that the nose is over the knee and toe involves a shift too far to the side. The result is greater side-to-side motion of the trunk and more time spent on each skating stroke. This decreases the skating tempo, the stride frequency being used, and may have a negative impact on skiing speed.

In short, be cautious about simplifications regarding ski technique. The finest skiers often break the simple guidelines and go beyond those to use physics, anatomy, and their physiological attributes to best advantage.

From techniques to economy

Most ski-training is carried out at much lower velocity than race pace so the economy of skiing is improved at that low velocity. However, this raises the question as to how to improve the economy of skiing at race pace.

The traditional approach, emphasized by world-class skiers, is to increase the cruising velocity of distance training, especially the velocity of fast distance training; to use natural interval training, including sections at race pace; and to use interval training at race pace. The attention has to be put not only on the skiing techniques and economic skiing, but also on the development of aerobic or anaerobic endurance characteristics. Comparisons of the training of international and national level skiers have shown that the training volume of the skiers may be equal in hours but the average cruising velocity and the velocity of fast distance training of the world-class skiers is higher than that of national level skiers.

Training at race pace increases blood lactate concentration to 5–10 $\text{mmol}\cdot\text{l}^{-1}$ after 1–1.5 km skiing and the increased acidity may influence muscle force production, relaxation and coordination of movements. To decrease blood lactate accumulation and to increase the volume of training at race pace, shorter distances, which allows increasing the number of repeats, have also been used to improve the economy at race pace, e.g. 3–10 × 0.5–1 km at race pace with 5–10-min intervals at low velocity.

One relatively new way to increase the volume of training at race pace without increasing blood lactate concentration is to include short sprints at race pace into low-intensity distance training. The duration of sprints can vary between 20 and 60 s, and low-intensity skiing at normal low-intensity aerobic distance training pace is done for 2–5 min between sprints. Blood lactate concentration stays at a low level because the energy for sprints comes mainly from phosphocreatine (PCr) and oxygen stores in the muscles which are replenished between sprints. As an example, three sets of 10 × 30 s with 2–3 min interval between sprints and a 5–10-min interval between sets allows 15 min skiing at race pace during a 2-h distance training session without increase in blood lactate concentration. Figure 3.16 shows the average blood lactate concentration of national team skiers who did seven sprints of 10, 20 and 30 s duration at race pace with 2–3-min intervals during their low-intensity distance training, indicating that this kind of training can be used to increase the volume of training at race pace without increasing blood lactate concentration.

Main points to remember about training for improving skiing techniques

- Skiing speed depends on generating propulsive force and minimizing the drag forces acting against a skier's motion.
- Establishing mental images of highly skilled technique is part of a skier's development; this is probably best accomplished with many skilled skiers being watched, but can be supplemented with appropriate video examples of elite skiers.
- It is more helpful to visualize and reinforce the image of highly skilled technique with video illustrations and skiing with skilled companions than to repeatedly point out errors in a skier's technique.
- An advantage of dry-land training is the opportunity to focus on an isolated part of ski technique, such as poling, without being distracted by other components of the full movement pattern.
- Isolating technique components and focusing on a single technique over a fixed lap can be instructive for skiers.
- As a skier evolves personal technique toward highly skilled patterns, progress can be assessed through a variety of relatively simple measurements which can also help direct technique adjustments. Ultimately, the goal of coaching and skier self-evaluation is to enhance a skier's kinesthetic sense of ski and snow interaction and how individual body characteristics of strength, endurance and power influence propulsive force generation.
- Improved skiing technique has to be transferred into improved economy of skiing at race pace and when fatigued by increasing the cruising velocity during distance training and by interval training at race pace.
- Including short sprints at race pace into low-intensity aerobic distance training sessions can increase the volume of training at race pace without increasing lactate concentration.

Training plan

The physiological and biomechanical factors that differentiate elite skiers from other ski-racers are well known. It is also known that different training philosophies and methods are applied in different countries by elite coaches with similarly successful results. Although there is very little information on how to develop the most effective training programme for a cross country skier, this section presents some data and aspects of training based on studies, practical experiments and training logbooks of successful world-class skiers.

An important principle is that a skier can attain the world-class level only with his or her strong characteristics. Follow-up measurements on several world-class skiers have indicated that too much emphasis on weak characteristics does not improve race performance and may even impair their strong characteristics. Therefore, the coach has to find and train those individual strong characteristics a skier has while his or her weaknesses should only be improved so far that they do not limit the full development and utilization of the strong characteristics. This principle also emphasizes that each skier must have an individual training programme based on his or her own performance characteristics and training background.

Development of volume of training with age

As children most elite skiers have had a broad-based training, practised different sports and developed their coordination skills. Their talents as skiers have also been obvious and many have been successful skiers at school. However, some skiers may have matured quite late and have not necessarily performed well in cross country skiing before the age of 15–16 years.

Regular training of elite skiers usually begins at the age of 12–16 years. At that age the most important feature that must be developed is skiing technique and related neuromuscular characteristics, which emphasize the importance of a broad-based training at that age. Young skiers should also learn to ski fast. In practice this suggests that the duration of training sessions of junior skiers should not be too long because low-intensity distance training may impair force–velocity characteristics and create slow skiing memory engrams in the CNS. The frequency of training guarantees the development of aerobic endurance characteristics.

After puberty, at the age of 16–20 years, the emphasis in training is put on the development of $\dot{V}O_{2max}$, and on the increase of muscle mass and muscular endurance of the upper body double poling muscles and on ski-specific training as a whole. The ability to ski fast with good skiing techniques must be maintained and improved and the velocity of distance training should be increased. It has been suggested that the years before puberty might be most favourable for the development of heart size and function and $\dot{V}O_{2max}$ but, as shown in Fig. 1.13, the period after puberty seems to be more important. Skiers and their coaches often increase the training volume considerably after puberty. However, this should not be done at the expense of intensive training aimed at keeping up and developing the neuromuscular performance characteristics important for fast skiing. Many present world-class skiers had only two or three summer training periods of 1–2 weeks and one 2-week ski-training period on snow with emphasis only on low-intensity distance training when they were this age.

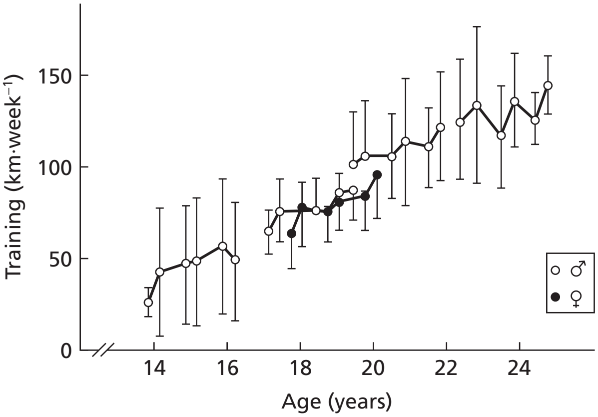


Fig. 3.20 Increase in the annual total training volume of Finnish cross country skiers expressed in average weekly training distance (mean ± SD). (From Rusko 1992.)

Natural interval training with different velocities of skiing is more feasible than prolonged training at low velocity and intensity. Some world-class skiers use short fast sprints at the end of their prolonged low-intensity training sessions to keep up their ability to ski fast.

The annual volume of training of Finnish skiers (calculated as the mean weekly volume during the year) increases from about 50 km·week^{-1} and six times per week at the age of 14–15 years to about 100 km·week^{-1} and eight times per week at the age of 20 years (Fig. 3.20). Thereafter, the training volume increases to 140–150 km·week^{-1} and 8.5 times per week at the age of 25 years. The training frequency starts to plateau after the age of 18 years. Female skiers train almost as much and as frequently as male skiers after puberty but adult female skiers train a little less than males. The proportions of skiing (40–50%), roller skiing (10–20%) and running ski-walking (35–45%) varies more between skiers than between different age groups or nationalities but elite adult skiers have a high proportion of skiing on snow and roller skiing (70%). The training volumes of Finnish skiers correspond well with those of Swedish skiers (Table 3.6). Data from world-class Norwegian skiers also indicate that at the age of 13–17 years their mean weekly amount of training has been 10–15 h·week^{-1}, 15–25% of their training was done at medium to high intensity (85–95% of HR_{max}) and the volume of

Table 3.6 The amount of training for cross country skiers in different age groups in Sweden in 1990s. Warm-up and stretching exercises are not included in the figures. (From Bergh & Forsberg 1992.)

		Amount of training (h/year)	
	Age (years)	Males	Females
Seniors	> 20	650–750	500–700
Juniors	16–20	400–550	300–550
Youth	12–16	250–350	250–350

roller skiing was 25–35% during the dry-land season. Table 3.7 shows the development of training of a junior skier who later won the world championship title.

Seasons and periods of training

In skiing countries, snow usually falls at the end of October or the beginning of November and melts in April. Consequently, the year-round training programme includes both dry-land and on-snow training seasons. Elite cross country skiers also have ski-training camps on snow during summer months when they go to ski on the glaciers, e.g. in central Europe.

Traditionally, the dry-land and on-snow seasons have been divided into shorter seasons with different training emphases. During basic summer training period the prerequisites for more demanding training in the autumn and winter seasons are developed. The distance training volume is high and the intensity is low. General strength and muscular endurance training is included for increasing muscle mass or/and improving neuromuscular determinants of endurance performance. During the autumn season the volume of intensive interval-type training starts to increase, $\dot{V}O_{2max}$, RCT and LT are improved and ski-specific muscular endurance training becomes more important. The on-snow skiing season usually starts with a period of low-intensity high-volume ski-training of a few weeks, after which $\dot{V}O_{2max}$ training and skiing velocity are emphasized. Thereafter, performance peaking for the most important races of the year starts. This is still the most common approach for planning the training seasons of junior and adult skiers (Fig. 3.21).

Regardless of emphasizing performance and performance peaking during the racing season, skiers should keep up a certain level of low-intensity aerobic endurance training during the winter racing season. Findings on the development of $\dot{V}O_{2max}$, LT and RCT for two subgroups of national team female skiers who had either very successful ($n = 2$) or very unsuccessful ($n = 2$) racing seasons indicate that both subgroups improved all their endurance characteristics during the summer training period but $\dot{V}O_{2max}$, LT and RCT of unsuccessful skiers decreased considerably from autumn to winter. Successful skiers maintained their LT and RCT and slightly improved their $\dot{V}O_{2max}$ from autumn to winter. These findings are in line with data showing that the oxidative capacity of muscles decreases considerably during the racing season.

After 20 years of age the planning of the training year focuses more and more on training periods for improving individual strong characteristics and weaknesses. During each period some important (limiting) determinants of performance are emphasized in training. The duration of different periods may range from a few days (overreaching period) up to several weeks, after which a new period with a new emphasis is started. The duration of periods can be based on the findings that different muscle strength and aerobic endurance characteristics develop quite well during the first weeks of training but then a plateau is observed. This can be seen in Fig. 3.2 for $\dot{V}O_{2max}$. Similar figures can be found for submaximal blood lactate decrease and muscle strength increase (Åstrand & Rodahl 1986). The half-time of increase (and decrease) in activity of many oxidative enzymes is around 1 week. Typically, the training emphasis is done so that 2–4 training sessions of the week are directed to improve the targeted characteristics. Recovery periods of 1–6 days guarantee that the transfer into improved performance is possible.

In cross country ski-training the most common emphasis assignments for the different training periods can be summarized as follows (see also Table 3.8).

- Improvement of basic aerobic endurance, e.g. by high-volume low-intensity distance training (volume training period).
- Improvement of $\dot{V}O_{2max}$, e.g. using interval-type high-intensity training (intensive training period for improving $\dot{V}O_{2max}$).

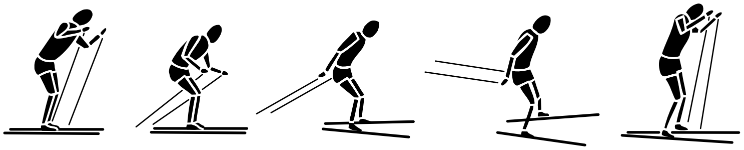


Table 3.7 Summary of training of a male skier from the age of 13 years to a world champion at the age of 30 years.

Age	Volume (km)	Volume (h)	Skiing (km)	Roller skiing (km)	Running hiking (km)	Strength (times/h^{-1})	Slow and fast distance training (%)	Tempo training (%)
13	2564	280	834	–	1730	23 times	Approx. 80	Approx. 7
14	3704	390	864	–	2840	19 times	Approx. 80	Approx. 8
15	4190	420	1804	26	2360	55 times	77	8
16	4471	450	1755	498	2238	60 times	79	11
17	6059	600	2417	843	2799	80 times	77	13
18	6349	610	3000	830	2519	80 times	80	10
19	5935	580	2665	824	2446	56 h	81	10
20	8201	635	4509	1450	2242	49 h	80	12
21	8030	560	5166	1163	1701	18 h	83	13

For the last two seasons, the method of calculating the hours has changed to an approximate 20% decrease compared to previous years because only effective training time is included.
Distance training includes low intensity (basic endurance, between LT and RCT, sometimes below LT) and fast (pace endurance, ≤ RCT) distance training.
Tempo training includes workouts at anaerobic threshold (RCT) and up to race pace. Short anaerobic intervals are also included here (training where lactate production is faster than lactate removal). Speed training and strength training are not included.

Age	Volume (km)	Volume (h)	Skiing (km)	Roller skiing (km)	Running hiking (km)	Strength (h)	Slow distance training (%)	Fast distance training (%)	Tempo training (%)
22	7574	513	4633	1344	1597	19 h	70	15	12
23	8697	604	5951	1263	1358	48 h	64	16	12
24	8226	547	4565	1750	1911	38 h	65	14	14
25	9285	632	6272	1584	1465	67 h	61	17	11
26	8374	572	5694	1313	1367	53 h	66	14	9
27	11010	813	5915	2218	1661	84 h	78	6	5
28	13294	981	8704	2311	1420	85 h	78	7	5
29	11040	785	7230	2098	1385	65 h	74	9	7
30	9669	737	5590	2169	1767	104 h	66	11	8

The total annual volume (km) includes rowing, kayaking, and half of the mountain biking kilometers.
The total annual volume (h) is the effective training time, and does not include breaks during a workout.
Skiing and roller skiing (km) include both classical and skating techniques.
The category of running and hiking (km) also includes hill striding workouts.
Strength training (h) includes general circuit training and weight workouts, but not specific strength training on skis or roller skis, or with ski poles.
Slow distance training includes recovery workouts, warm-ups and cool-downs, and basic endurance workouts that go up to or slightly above the aerobic threshold.
Fast distance training includes the obvious fast portions of distance workouts; lower heart rate limit is about 5 beats above LT (aerobic threshold) and upper heart rate limit at RCT (anaerobic threshold).
Tempo training includes competitions and training above RCT (hard distance, interval-type maximal endurance training, and short anaerobic intervals).

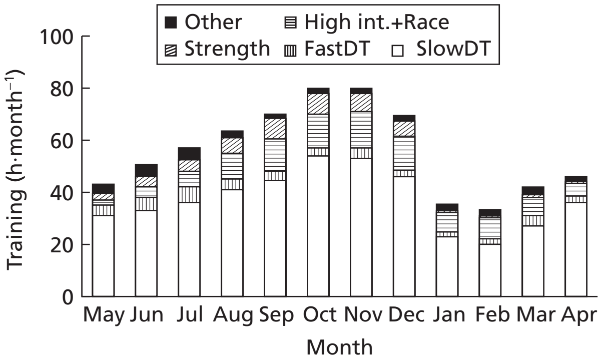


Fig. 3.21 Histogram showing the monthly volume of training from the age of 15–16 years performed by another world champion skier. Low-intensity distance training (SlowDT), HR 120–160 b.p.m., 60–85% HR_{max} (190 b.p.m.); fast distance training (FastDT), HR 161–171, 85–90% HR_{max}; high intensity training and races, HR 172–190, 90–97% HR_{max}. (Modified from Ingjer 1992.)

- Improvement of fatigue resistance, e.g. using fast distance training and muscular endurance training (fatigue resistance period).
- Improvement of force–velocity characteristics, muscle recruitment and muscle power, e.g. using explosive-type strength, sprint and power training (strength and muscle power period).
- Improvement of skiing techniques and economy of skiing.
- Improvement of upper body strength, muscular endurance or $\dot{V}O_{2max}$.
- Improvement of oxygen transport capacity of blood by altitude training or living high, training low approach.

The feedback from several world-class skiers is that the cornerstone of their training is a lot of training close to race pace with a competition-like technique and force production, in order to improve:

- maximal oxygen uptake;
- race pace velocity;
- the economy of skiing at race pace;
- the ability to ski for a long time at race pace (fatigue resistance);
- performance capacity of the upper body;
- the velocity reserve (difference between race pace and maximal skiing velocity); and
- the ability to make quick tempo changes.

In addition, the quality of training is a key point. The number of training sessions that improve performance capacity must be increased and the number of unproductive training sessions must be minimized. Control exercises are continuously performed and the training state, including signs and symptoms of overtraining, is followed using methods described in the next section. Skiers should learn to 'listen' to the signals of their own body, both during training and recovery. They should also learn to adjust the training plan promptly according to the received feedback from their body. To be able to attain world-class level skiers must have learned to understand their training as a whole, as well as the goals of individual workouts and training periods.

World-class cross country skiers have to plan their training to take into account that the first international races are now in November and that the racing season, including the World Cup races, can continue until March–April. Together with increased skiing velocity and the importance of neuromuscular factors, elite skiers have to plan their training so that peak performance can be attained within a couple of weeks' peaking during the whole training season.

The differences in the training for sprint skiing and for longer ski-races depend on the relative importance of specific performance determinants in that race. Each skier and coach must decide that themselves but the following percentage distributions can be used as a guideline for such decisions (Table 3.9).

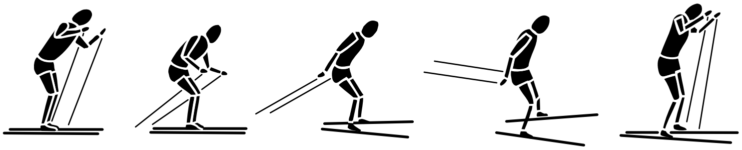
Main points to remember about a training plan

- Skier and coach have to find and train the strong characteristics of the skier.
- During junior years ski technique and the ability to ski fast must be improved.
- Total training volume increases with age but should not be at the expense of developing fast skiing and $\dot{V}O_{2max}$.
- Traditional training seasons are changing into periods when the training of one or more important determinant of performance is emphasized at a time.
- At world-class level the number of training sessions that improve performance must be increased and those that are unproductive must be minimized.

Control of training

In cross country skiing the weather conditions have so great an influence on the velocity of skiing on snow

Table 3.8 Training data and aerobic endurance characteristics for intensive (IT), distance (DT) and normal (NT) training group during experimental 4-month summer training period. The young (16–21 years) male and female skiers had similar percentage ST fibre composition in their vastus lateralis muscles. The differences between groups were small but only distance training increased RCT in percentage of $\dot{V}O_{2max}$ whereas intensive training seemed to increase $\dot{V}O_{2max}$ the most.



		IT ($n = 48$)	NT ($n = 90$)	DT ($n = 57$)
Total training volume				
km·week^{-1}		84 ± 17	85 ± 25	108 ± 33††
times per week		6.9 ± 1.4	6.8 ± 1.4	7.4 ± 1.5†
Intensive training				
km·week^{-1}		11.0 ± 3.9††	6.6 ± 3.9	5.1 ± 2.8
times per week		2.4 ± 0.7††	1.5 ± 0.7	1.1 ± 0.5
percentage of total		13.2 ± 4.3††	7.5 ± 3.4	4.6 ± 2.1
$\dot{V}O_{2max}$ cycling (ml·kg^{-1}·min^{-1})	Pre	58.2 ± 7.4	59.2 ± 7.6	61.0 ± 7.5
	Post	60.6 ± 6.8***	60.5 ± 6.8*	61.9 ± 8.1
$\dot{V}O_{2max}$ ski walking (ml·kg^{-1}·min^{-1})	Pre	62.8 ± 7.4	63.5 ± 7.4	65.9 ± 8.4
	Post	65.4 ± 6.6***	65.1 ± 7.2***	68.4 ± 8.9***
RCT cycling (ml·kg^{-1}·min^{-1})	Pre	43.2 ± 4.6	43.4 ± 4.5	45.1 ± 4.3
	Post	44.4 ± 4.3**	44.7 ± 4.2**	46.7 ± 5.0***
RCT percentage $\dot{V}O_{2max}$	Pre	72.6 ± 5.7	71.9 ± 6.3	72.2 ± 5.6
	Post	71.6 ± 4.7	72.6 ± 5.1	73.8 ± 5.4*

Significant change: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.
Significant difference between IT and DT groups: $\dagger P < 0.05$; $\dagger\dagger P < 0.001$.
Intensive training denotes training where heart rate or velocity is increased to or above the level corresponding to the RCT (individual anaerobic threshold) 0–25 b.p.m. below maximal heart rate.

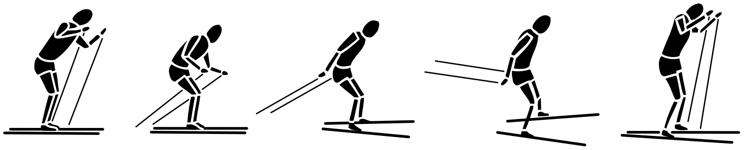


Table 3.9 Importance of different determinants for different ski races.

Ski race	Aerobic endurance (oxygen transport and oxidative energy yield)	Economy (skill and technique)	Skiing power (neuromuscular and anaerobic factors)
Sprint	50	25	25
5–10 km	55	25	20
30–50 km	65	25	10

that it is difficult to use similar performance tests as in running or swimming. Therefore, combinations of field and laboratory tests including different physiological measurements have been developed.

Performance testing in field conditions

During the dry-land season the simplest method to analyse the development of performance capacity is to perform a running or roller skiing time trial over a predetermined control track and to measure heart rate during that time trial. The environmental conditions may slightly influence performance but the skier and coach can evaluate the performance taking into account the heart rate, subjective feelings, time/velocity and techniques of the performance. The time trial is performed before and after each training period to control the effects of that training period. If the duration of the time trial is 5–10 min it gives rough information on the development of $\dot{V}O_{2max}$ and related characteristics. For evaluating fatigue resistance, the duration of the time trial should be close to the duration of the race performance, depending on the age and typical race distance of the skier. The changes in fatigue resistance are evaluated from the performance time, subjective feelings, heart rate and heart rate increase during the time trial and from post-trial heart rate recovery. Measurement of post-trial peak blood lactate concentration can also be used to interpret the changes in performance capacity.

During the on-snow season the environmental conditions vary from day to day and within a day and make it difficult to use performance measurements. Therefore, heart rate during and blood lactate after skiing a predetermined test lap of 1–3 km at 3–5 different skiing velocities from slow distance training velocity to race pace velocity are measured (see Figs 3.7, 3.11, 3.12 and 3.22). A typical approach is to ski at three self-estimated velocities that correspond to LT intensity, RCT intensity and race pace (Fig. 3.22). Another approach is to use laboratory-determined threshold heart rates and heart rate monitor as guides for skiing velocities. The skiing times alone do not tell if or why the performance capacity has changed. However, from blood lactate–velocity and heart rate–velocity curves it is possible to evaluate if the velocities used are those intended. The blood lactate–heart rate curve can also be used to check if the laboratory-determined threshold heart rates are correct in field conditions. If the blood lactate–heart rate curve moves towards the right, the performance capacity of the skier has probably improved; however, it does not tell whether $\dot{V}O_{2max}$, $BLaSs_{max}$ or skiing economy has improved. Subjective feelings, evaluation of performance and recovery in connection to these ski-training exercises as well as comparison with the other skiers in the team improve the interpretation of results.

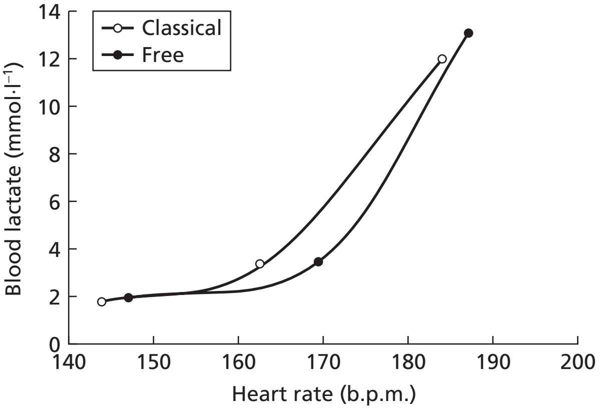


Fig. 3.22 Blood lactate–heart rate during diagonal and freestyle skiing best fit curves from data of eight junior skiers ($\dot{V}O_{2max}$ of 78 ± 2 ml·kg^{-1}·min^{-1}) at three velocities corresponding to LT, RCT and race pace. Measurements were taken in the ski tunnel of Vuokatti Sports Institute, Finland, in controlled weather conditions. (Modified from Hynynen *et al.* 1999.)

In European countries several national ski-teams have used an indoor submaximal treadmill running (or cycle ergometer) test with heart rate and blood lactate measurements to evaluate the effects of different training periods. Three to five stages of 4-min duration at progressively increasing intensity corresponding to the intensity range of 50–90% of $\dot{V}O_{2max}$ have been used. In Fig. 3.23 heart rate and blood lactate data from a Finnish national team female skier have been presented. In Fig. 5.16 similar results during an altitude training camp are presented. Decrease in blood lactate concentration and heart rate indicates a positive training effect. The indoor treadmill exercise evaluates the performance of the skier in standard conditions independent of environmental factors which influence the performance and physiological responses during outdoor measurements. However,

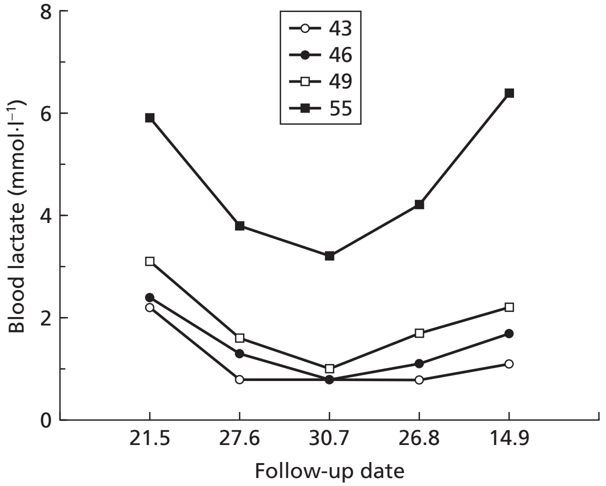


Fig. 3.23 Blood lactate concentration of a national team female skiers during 4 × 4-min treadmill running at a velocity of 11.7 km·h^{-1} at four different inclinations ($\dot{V}O_{2demand}$ 43, 46, 49 and 55 ml·kg^{-1}·min^{-1}, respectively) at five different time points. The curves indicate a positive training effect until July and unfavourable development after that. (Rusko, unpublished data.)

the test results do not tell what physiological characteristics have improved.

During the on-snow season, time trials can be used for comparing skiers. In Norway, 1 km double poling time trial has been used to evaluate upper body strength and endurance. The neuromuscular and muscle power factors related to skiing techniques and the ability to ski fast can be evaluated by using short skiing sprints at progressively increasing velocity (see the section on Technique training).

Laboratory measurements of performance characteristics

Laboratory measurements allow a thorough evaluation of the performance capacity and related physiological characteristics of the skier. Laboratory tests and measurements can be used to evaluate the strong characteristics and weaknesses of a skier, to evaluate the training effects and to prescribe heart rate zones for endurance training. Laboratory testing also gives information on aerobic, anaerobic and neuromuscular characteristics (Fig. 3.24).

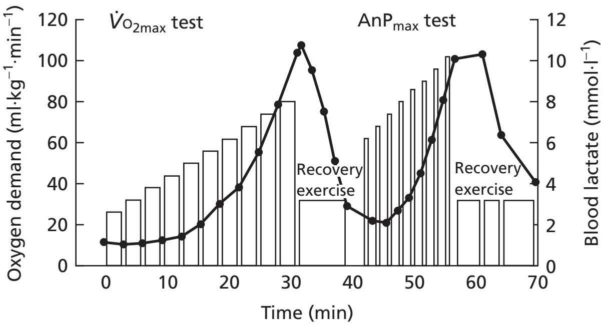


Fig. 3.24 Description of the test protocol of cross country skiers in the laboratory on treadmill and subsequent blood lactate changes. The $\dot{V}O_{2max}$ test is performed first then, after a recovery exercise to decrease blood lactate concentration, the maximal anaerobic pole striding test (n × 20 s/100 s, AnP$_{max}$ test) is repeated until exhaustion. Before the tests as well as before and after the AnP$_{max}$ test, CMJ height can be measured to obtain more information on the neuromuscular force–velocity characteristics (see text for further explanation).

Treadmill testing for $\dot{V}O_{2max}$ *and aerobic endurance*

The basic laboratory test is an incremental treadmill ski-walking/ski-striding test using ski poles to exhaustion for determining $\dot{V}O_{2max}$, RCT and LT. The duration of each stage is 3–4 min. The starting intensity and the intensity increases are selected so that the number of stages is 7–10 and the total duration of the test is 20–30 min (Fig. 3.24). Blood sampling is performed during 20-s breaks after the end of each stage and oxygen uptake and heart rate are measured continuously during the test. Adult athletes usually attain high $\dot{V}O_{2max}$ in this test while some female and young skiers with limited muscular endurance may attain 1–3 ml·kg^{-1}·min^{-1} lower $\dot{V}O_{2max}$ in this test compared to a shorter test where the thresholds cannot be determined or they are inaccurate.

Typical changes in blood lactate concentration and respiratory variables have been described in Figs 3.5 and 3.24.

The $\dot{V}O_{2max}$ is defined as the highest 1-min oxygen uptake during the test. The highest 1-min value is often attained just before exhaustion without levelling off of oxygen uptake. $\dot{V}O_2$ is calculated in litres per minute (l·min^{-1}), milliliters per kilogram body weight per minute (ml·kg^{-1}·min^{-1}) and in milliliters per kilogram body weight raised to the power of two-thirds per minute ($ml \cdot kg^{2/3} \cdot min^{-1}$; see Chapter 1).

The LT is determined as the starting point of blood lactate accumulation, e.g. 0.5 $mmol \cdot l^{-1}$ increase above blood lactate level during preceding rest and lower intensity exercise stages. The first unlinearity in lung ventilation–oxygen uptake curve is usually observed close to LT. The RCT is defined as the starting point of accelerated CO_2 output and ventilation and decreased end-tidal CO_2 concentration in relation to O_2 uptake when exercise intensity is further increased above LT. Blood lactate concentration at RCT is individually ~2–5 $mmol \cdot l^{-1}$ and the blood lactate accumulation starts to accelerate close to RCT. To calculate the percentage value of LT and RCT, the resting $\dot{V}O_2$ of 5 $ml \cdot kg^{-1} \cdot min^{-1}$ is first subtracted from the threshold $\dot{V}O_2$ and $\dot{V}O_{2max}$. In previous European literature the terms 'aerobic threshold' and 'anaerobic threshold' have also been used and they correspond approximately to the LT and RCT, respectively. There are no generally accepted methods for the determination of LT and RCT so it is best to use the same laboratory and testing staff, which guarantees comparable threshold values. Typically, $\dot{V}O_{2max}$ and thresholds are measured in the laboratory 2–5 times during the season.

Reference values for elite skiers have been presented in Chapter 1 and in a previous section of this chapter. Table 3.10 gives reference values based on several hundred test results of Finnish cross country skiers. If the category of the characteristics is low or below average, that characteristic should be emphasized in training, e.g. by having some training periods for improving that characteristic specifically. The average annual increase in $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$ and $ml \cdot kg^{2/3} \cdot min^{-1}$) is 4–7% in skiers below 16–17 years, 2–5% between 17 and 20 years of age and 0–3% above 20 years. The LT and RCT of elite skiers are 65–70 and 80–85%, respectively. If the threshold values are close to $\dot{V}O_{2max}$, $\dot{V}O_2$ itself may set the limit for further development of the thresholds and training periods for increasing $\dot{V}O_{2max}$ should be considered. In addition to the threshold values, lactate–$\dot{V}O_2$ and lactate–heart rate curves can be re-examined. Blood lactate–heart rate curve can be used for determination of threshold heart rates that can be used as intensity guidelines during training. High submaximal lactate values at low $\dot{V}O_2$ and heart rate as well as high lactate values at LT and RCT suggest that oxidative capacity, fat utilization and lactate clearance from blood should be improved. However, it must be remembered that lactate level also depends on preceding meal or diet, excitement, etc. After a carbohydrate meal lactate level can be 1–2 $mmol \cdot l^{-1}$ higher than after a mixed meal with 50% fat and 15–20% proteins. Similarly, stress hormone secretion can increase lactate level by 1–2 $mmol \cdot l^{-1}$.

Testing for upper body $\dot{V}O_{2max}$ and aerobic endurance

Different upper body double poling ergometers have been constructed for the evaluation of upper body power and $\dot{V}O_{2peak}$. Each laboratory use their own devices but the testing protocol should be about the same as that presented for the treadmill testing above. After warming up and a short break, the athlete performs 2–4-min exercise stages progressing in intensity from 60% of $\dot{V}O_{2peak}$ in 20-W steps until exhaustion. Blood sampling is performed during 20-s breaks after the end of each stage and oxygen uptake and heart rate are measured continuously during the test. $\dot{V}O_{2peak}$ as well as LT and RCT are calculated in a similar fashion to the whole body pole striding treadmill test. Upper body $\dot{V}O_{2peak}$ should be 80–90% of whole body $\dot{V}O_{2max}$ and upper body $\dot{V}O_2$ at RCT about 80–90% of upper body $\dot{V}O_{2peak}$. Figure 3.10 shows that during double poling on a ski ergometer a world champion male skier attained a $\dot{V}O_{2peak}$ of 86% of the $\dot{V}O_{2max}$ during pole striding on a treadmill and that the blood lactate–heart rate curve was different during upper body exercise as compared to whole body exercise.

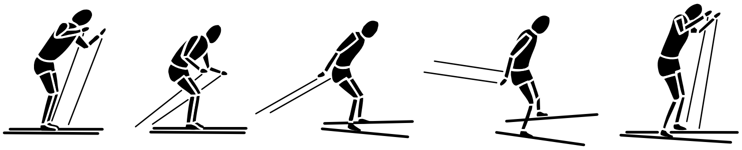
Upper body $\dot{V}O_{2peak}$ and thresholds can also be measured during double poling on snow or on an indoor track using roller skis or roller skates and a portable device for measuring $\dot{V}O_2$ uptake (e.g. Cosmed K4). A typical approach is to double pole at three self-estimated velocities that correspond to LT, RCT and race pace intensity. A similar exercise protocol as on a double poling ergometer can also be used, e.g. 3–4 min double poling stages with progressively increased velocity until maximal velocity.

Testing for neuromuscular and maximal anaerobic skiing power characteristics

Force–velocity characteristics of the neuromuscular system are usually measured when muscles are well

Table 3.10 Finnish reference values for: (a) $\dot{V}O_{2max}$ test; and (b) maximal anaerobic pole striding test (AnP_{max} test) on treadmill. The test result is expressed as the oxygen demand of the last exercise minute before exhaustion ($\dot{V}O_{2max}$ test) and as the oxygen demand of the last 20-s exercise period before exhaustion (AnP_{max} test). The measured $\dot{V}O_{2max}$ can also be used if the $\dot{V}O_2$ measurement device is well calibrated before and after the test and is quality controlled. The oxygen demand of pole walking and pole striding on treadmill is calculated according to Balke & Ware 1959: $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) = 1.78 × v (m·min^{-1}) × [(g + 7.3)/100], where v = velocity in m·min^{-1} and g = percentage angle of the slope. The classification of reference values is as follows.

1 Municipal level
2 Regional/provincial level
3 National level
4 National championship level
5 World-class level



(a) $\dot{V}O_{2max}$ test

$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	1	2	3	4	5
Adult male skiers	< 66	66–73	73–78	78–81	> 81
Boys 15–18 years	< 56	56–62	62–68	68–71	> 71
Adult female skiers	< 56	56–62	62–68	68–71	> 71
Girls 15–17 years	< 48	48–53	53–58	58–61	> 61

(b) AnP_{max} test

AnP_{max} (ml·kg^{-1}·min^{-1})	1	2	3	4	5
Adult male skiers	< 116	116–126	126–136	136–150	> 150
Adult female skiers	< 100	100–109	109–118	118–130	> 130
CMJ_{Pre} (cm)					
Adult male skiers	< 35	35–40	40–45	45–50	> 50
Adult female skiers	< 25	25–30	30–35	35–40	> 40

recovered or rested. Typical field measurements are 5-jump, CMJ, bench press, sit-up and similar muscular strength and endurance tests.

As described in Chapter 1, the maximal anaerobic running test (MART) has been developed for the determination of neuromuscular, anaerobic and muscle power characteristics of athletes. The original version consists of *n*·20-s runs on a treadmill with a 100-s recovery between runs. The starting velocity of the treadmill is 3.7 m·s^{-1} at inclination of 4° and the velocity is increased by 0.35 m·s^{-1} for each consecutive 20-s run until exhaustion. This increase corresponds to ~5–6 ml·kg^{-1}·min^{-1} increase in the $\dot{V}O_2$ demand for inclined treadmill running. The blood lactate concentration is measured after each run and 2.5 and 5 min after exhaustion. The height of CMJ can also be measured before the test as well as immediately (2.5 and 5 min) after exhaustion. The highest velocity, V_{MART}, or power calculated as the oxygen demand, AnP_{max}, is used as the index of maximal anaerobic running power. Based on blood lactate–running velocity/power curve, submaximal indices of anaerobic running power can also be calculated and expressed as the velocity (or power as the oxygen demand of running) at a submaximal lactate concentration.

Cross country skiers have also used a pole-striding modification of the original MART-test (Fig. 3.24). This AnP_{max} test is usually performed after the traditional $\dot{V}O_{2max}$ test with blood lactate measurements taken after each '20-s pole striding sprint' (Fig. 3.24). The velocity of the treadmill is initially 9 $km \cdot h^{-1}$ and inclination is increased gradually, e.g. from 9° ($\dot{V}O_{2demand}$ 62 $ml \cdot kg^{-1} \cdot min^{-1}$) to 16° ($\dot{V}O_{2demand}$ 98 $ml \cdot kg^{-1} \cdot min^{-1}$) for each consecutive '20-s sprint' and thereafter only velocity is increased to give a ~6 $ml \cdot kg^{-1} \cdot min^{-1}$ increase in the $\dot{V}O_{2demand}$ of the sprint until exhaustion (Fig. 3.24).

The results of the test give following information.

1 Maximal anaerobic running/ski-striding power or velocity (AnP_{max}, V_{MART}) has been used as a measure of maximal anaerobic muscle power (ability of the neuromuscular system to produce force and power when oxygen uptake and/or anaerobic energy production are high).

2 Peak blood lactate concentration after exhaustion is a rough measure of anaerobic capacity.

3 The height of CMJ before the test gives information on neuromuscular force–velocity characteristics at rest.

4 Blood lactate concentration at submaximal sprinting or striding velocities gives rough information on the economy of sprinting or striding.

5 The decrease in the height of CMJ because of exhaustion can be used as an estimate of neuromuscular fatigue resistance.

The velocity or power of the last completed sprint corresponds to 400 m sprinting power and the anaerobic contribution to the energy demand of the last completed 20 s sprint is about 70%. Test results have been shown to be highly reproducible.

The corresponding maximal anaerobic skiing power has also been measured as a maximal skating velocity during incremental sprint ski-skating on an indoor 200-m track (Fig. 3.25). The track is skated at progressively increased velocity starting from ~3.7 $m \cdot s^{-1}$ with 0.38 $m \cdot s^{-1}$ increases for each consecutive sprint until the sprint performance velocity levels off or the athlete is exhausted. Female world-class skiers have attained a higher maximal sprint skating velocity of 6.6 $m \cdot s^{-1}$ ($n = 5$) than medium class skiers, 6.1 $m \cdot s^{-1}$ ($n = 5$). Specialists in sprint skiing attained a similar maximal velocity as the other world-class skiers but their submaximal anaerobic sprinting velocity at the 3 mmol lactate level (V_{3mmol}, calculated from the blood lactate–skating velocity curve during the incremental sprint skiing test) was higher (6.1 $m \cdot s^{-1}$) than that of the other world-class skiers (5.8 $m \cdot s^{-1}$). Although the treadmill pole striding or indoor roller skiing AnP_{max} test modifications of the original MART are not so well established, the indoor sprint ski-skating version appears to be very good for evaluating the maximal anaerobic skiing power.

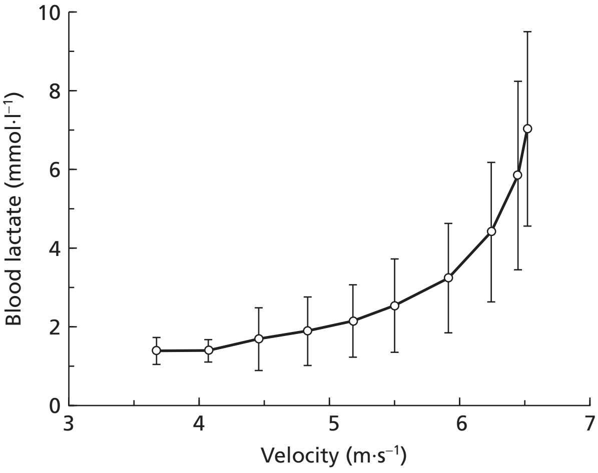


Fig. 3.25 Blood lactate curves (mean ± SD) for national team female skiers in an indoor roller skating AnP_{max} test. The skiers should have skied 0.38 $m \cdot s^{-1}$ faster during each consecutive 200-m lap after 200-m recovery lap but the two last velocity increases were only 0.21 and 0.07 $m \cdot s^{-1}$, respectively. Individual differences in peak blood lactate concentration were huge, suggesting neuromuscular limitation. (Rusko, unpublished data.)

There are also special ski-ergometers that can be used to measure upper body/double poling power. In those tests a 20-s incremental double poling exercise has been used, corresponding to the 20–25 s time to ski-skate the 200 m indoor track at maximal velocity.

The upper body power of female skiers was only ~65% of that of male skiers, indicating that the upper body power of female skiers is much lower than could be expected from their upper body $\dot{V}O_{2max}$, 76–81% of the male skiers. Upper body power has significantly correlated with race performance and with roller skiing $\dot{V}O_{2max}$.

Upper body power and fatigue resistance can also be evaluated using the double poling ergometer as the time to exhaustion at the power output eliciting $\dot{V}O_{2peak}$ (maximal aerobic velocity).

Blood analyses

Blood sampling and analyses can be used to evaluate more thoroughly the different medical aspects that influence training response. Most common blood properties include red and white blood cells, haemoglobin, haematocrit, ferritin. From the point of view of overreaching and overtraining it is possible to analyse the hormones describing the catabolic (e.g. adrenaline, noradrenaline, cortisol) and anabolic (e.g. testosterone, free testosterone, growth hormone) state of the body. Low levels of catabolic hormones and high levels of anabolic hormones indicate a good training state and potential for a good training response. The reverse situation indicates the possibility of approaching overtraining syndrome.

Analysis of creatine kinase, lactate dehydrogenase, urea, creatinine, immunoglobulins, etc., have also been used to evaluate the balance of anabolic and catabolic reactions and overtraining signs and symptoms.

Training logbook

The training logbook allows for calculation of exactly what has been done. This helps the skier and coach plan the training for the next week, month, season and year. The minimum requirement is to record the training modes, training volumes and training intensities.

The most important information from training modes is the volume and velocity of ski-training on snow (diagonal skiing, skating and double poling separately), other ski-specific training (ski-walking and ski-striding using poles, roller skiing), general dry-land training (running, cycling, rowing canoeing) and strength training.

The intensity of training is described as the volume of high-intensity endurance training aimed at improving $\dot{V}O_{2max}$ of the whole body and upper body. It includes fast distance and interval training at intensity/velocity between RCT and $\dot{V}O_{2max}$. Another important area is the so-called speed endurance training aimed at improving race pace velocity, i.e. training for improving maximal skiing velocity, as well as techniques of skiing and economy of skiing at race pace.

Traditionally, the volume of low-intensity aerobic distance training is also recorded but, in addition, information on training for improving fatigue resistance should also be obtained. Some characteristics can be trained for together, e.g. economy of skiing at race pace, $\dot{V}O_{2max}$, fatigue resistance. Therefore, each skier (and coach) has to decide how he or she records such training sessions. The volume of training must be expressed in both hours and minutes and kilometers so that the velocity of training can be calculated.

The more demanding the training is, the more important it is to record the recovery measures and/or factors that disturb recovery and increase non-training stress. The characteristics related to recovery from training are as follows.

- Volume of low-intensity short-duration training (<30 min) aimed at improving the recovery.
- Warming up and warming down exercises, including running, stretching, calisthenics, etc.
- Separate stretching and calisthenics sessions.
- Number of recovery days or half days, and number of nights with sufficient high quality sleep and those with insufficient or low-quality sleep.
- Additional means for improving recovery.
- Additional incidents that impair recovery and productivity, e.g. number of travelling days, crossing of time zones, loss of sleep, stress outside training.

The recovery means have also been presented in Chapters 5 and 6.

Summary of control of training

- Performance development in field conditions can be evaluated by using both time trials and submaximal treadmill running or ergometer cycling with heart rate and blood lactate measurements, but they do not indicate which determinant of performance has improved.

- Laboratory testing with sophisticated devices can evaluate changes in whole body $\dot{V}O_{2max}$ and upper body $\dot{V}O_{2peak}$ in controlled conditions.
- Portable $\dot{V}O_2$ measurement devices allow measuring whole body $\dot{V}O_{2max}$ and upper body $\dot{V}O_{2peak}$ in field conditions.
- Indoor skating (and double poling) modification of the maximal anaerobic running test gives information on maximal skiing power and related neuromuscular and anaerobic characteristics.
- The training logbook should allow calculation of the volume and velocity of training and measures of recovery.

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Chapter 4

Medical aspects of cross country skiing

The immune system

Organization of the immune system

In order to stay healthy and avoid infectious diseases, athletes need an optimally working immune system which can handle viruses, bacteria and other microbes encountered every day. The immune system—with its many cellular and soluble components—is dispersed throughout most of the body with connecting blood and lymph vessels as a communication web between the different immuno-active tissues (Fig. 4.1). There are no 'headquarters' in the immune system, in the way that the brain governs most of the nervous system. Nevertheless, certain immune cells and signal molecules circulating between the various organs and tissues have a paramount role in coordinating both local and systemic responses when the immune system is activated.

With regard to its strategic operations, the immune system resembles a military defence system with surveillance, resistance and attacking functions. These operations are closely integrated and essential for a well-functioning immune system, as intelligence service, air-raid shelters and missiles are important parts of a national defence system. However, the various immune cells and soluble components come

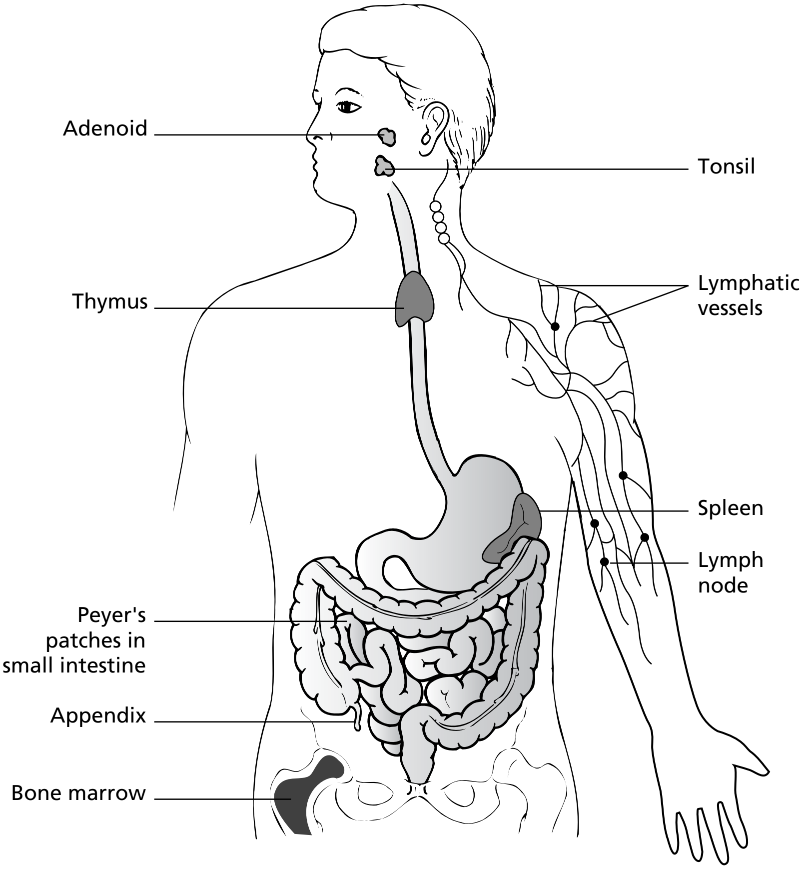

Fig. 4.1 The bone marrow is the birthplace of most immune cells. Some cells (B-lymphocytes) continue to mature in the bone marrow before they are deposited into the blood vessels, while other cells (T-lymphocytes) are transported to the thymus for further maturation. Lymphocytes and other immune cells then migrate through the blood circulation and lymphatic vessels to immuno-active tissues such as the spleen, lymph nodes and tonsils where they have a chance to meet and communicate with each other.

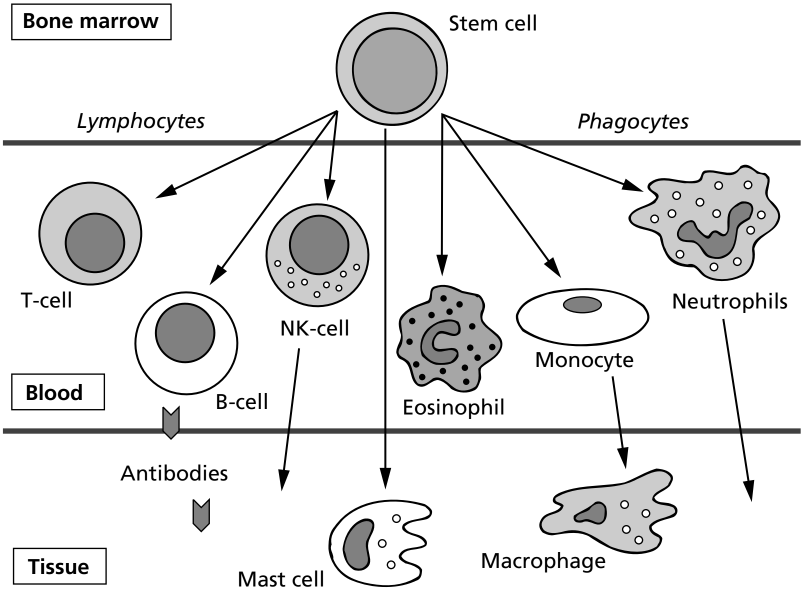

Fig. 4.2 The major cells of the immune system arise from a common stem cell in the bone marrow. The blood compartment contains mostly mature and specialized lymphocytes, neutrophil and eosinophil granulocytes, and monocytes. In the tissue outside the blood compartment, there are mast cells and macrophages (transformed monocytes) that have both phagocytic and secretory functions. Macrophages produce complement factors and cytokines while mast cells produce histamine, a trigger for allergic reactions.

into play in a different way, depending on whether the body is at rest (state of peace), or is being challenged (state of stress) or invaded by microorganisms (state of war). Additionally, the immune response depends on what type of stimuli activates the immune system. Physical activity and, in particular, strenuous exercise such as cross country skiing is a potent stimulus for the immune system, which may result in both activation and depression of several immune functions (see p. 103).

The first and most important task for the immune system, already starting in the embryonic stage, is the recognition and acceptance of itself. The immune system needs to establish codes for the molecular structure of all substances found in the body. This information is then stored on the 'hard-disk' in certain memory cells. In this way the immune system is able to distinguish between 'self' and 'non-self' (between the body's own tissue and foreign substances from the environment). Thus, the immune cells can direct their attack against foreign substances such as virus, bacteria, pollen, chemical agents, foreign cells, etc., without destroying the body's own tissue. However, we are able to develop tolerance for several environmental substances and thereby adapt to a coexistence with them without reactions in the immune system. The various colonies of protective bacteria (commensal microbes) in our throat and intestines are good examples of such beneficial coexistence. However, before going further into the various functions of the immune system, a short description of its components is warranted.

White blood cells (leucocytes) have many different characteristics and functions and can be divided accordingly into several subgroups. Figure 4.2 gives a schematic overview of the major immuno-active cells.

The body's overall defence against foreign substances and invading microbes (commonly designated 'antigens') may be divided into two systems.

1 An exterior *protective* system (physical and biochemical barriers) with the purpose of separating the internal milieu of the body from foreign substances in the environment. This is the body's first line of defence.

2 An interior *reactive* system (immune cells and soluble components), which is designed to locate and destroy those substances that are able to penetrate our physical and chemical barriers.

The interior immune system has two functionally different parts where the cells and soluble components make up the second and third lines of defence against invading substances. A schematic illustration of the cooperation between these three lines of defence against microbes or other foreign substances is given in Fig. 4.3.

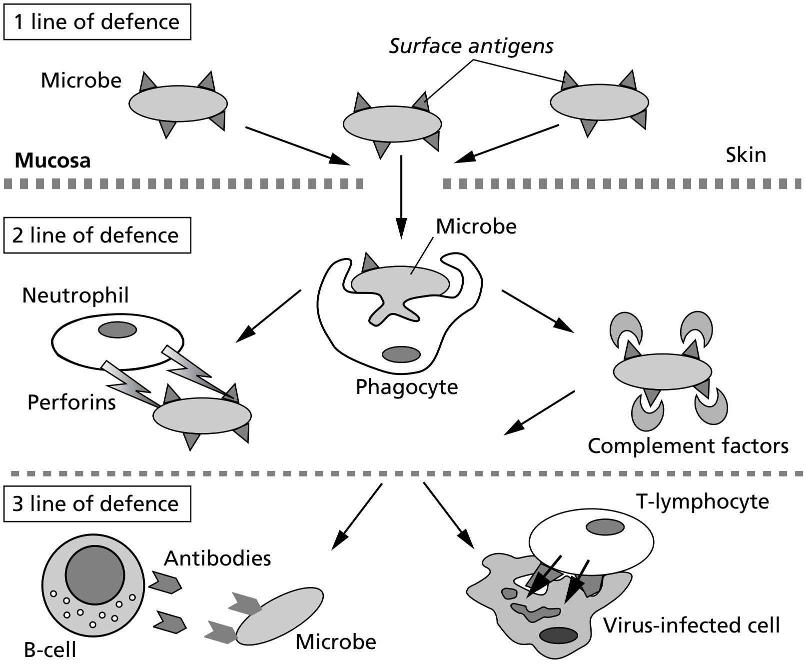

Fig. 4.3 The human body has several ways of protecting and defending itself from invading substances such as microbes. The skin and mucosal lining of airways, gut and genital tract are important parts of a first line of defence against microbes from our environment. If microbes are successful at penetrating this protective defence system, phagocytic cells (neutrophils and macrophages), natural killer (NK) cells and reactive components (oxygen radicals, enzymes and the complement factors) from the second line of defence will start an unspecific attack on the invading microbes. Subsequently, a third line of defence will kick in and use a cellular response (mainly T-lymphocytes) or a humoral response (mainly specific antibodies) to fight the invading microbe (see section on Fate of a microbe).

The protective first line of defence includes the following.

1 Physical barriers:
  (a) skin;
  (b) hair;
  (c) mucous membranes;
  (d) cilia of the airways.

2 Biochemical barriers:
  (a) acids/pH of the stomach, gut and urogenital tract;
  (b) enzymes in tears and saliva;
  (c) lipids and fatty acids in skin;
  (d) protective microbes in throat and gut.

The reactive second and third lines of defence include the following.

1 Immune/white blood cells:
  (a) lymphocytes—kill mostly virus, produces antibodies and cytokines;
  (b) neutrophils—eat mostly bacteria, produces inflammatory molecules;
  (c) monocytes—produce cytokines and inflammatory molecules;
  (d) macrophages—eat microbes, produce cytokines and inflammatory molecules;
  (e) mast cells—release substances which start allergic and inflammatory reactions.

2 Antibodies/immunoglobulins—molecules that bind microbes and antigens.

3 Complement factors—molecules that kill microbes and promote inflammation.

4 Cytokines—signal molecules for initiation and regulation of immune reactions.

The 'soldiers of the second army' of defence immediately attack all invading antigens in a non-specific way, using the same methods of destruction and elimination for all antigens. Almost conversely, the third 'army' of immune cells and soluble components first spend some time identifying specific characteristics of the invading enemy (antigen code), then it attacks with corresponding 'custom-made' weapons that are extremely effective, but only on the specific invader/antigen. Thus, the unspecific second line of defence has certain predetermined strategies and attacking weapons that come into immediate action (Fig. 4.4), while the specific third line of defence comes into action much later, when antigen/microbe-specific strategies and weapons are made (Fig. 4.5).

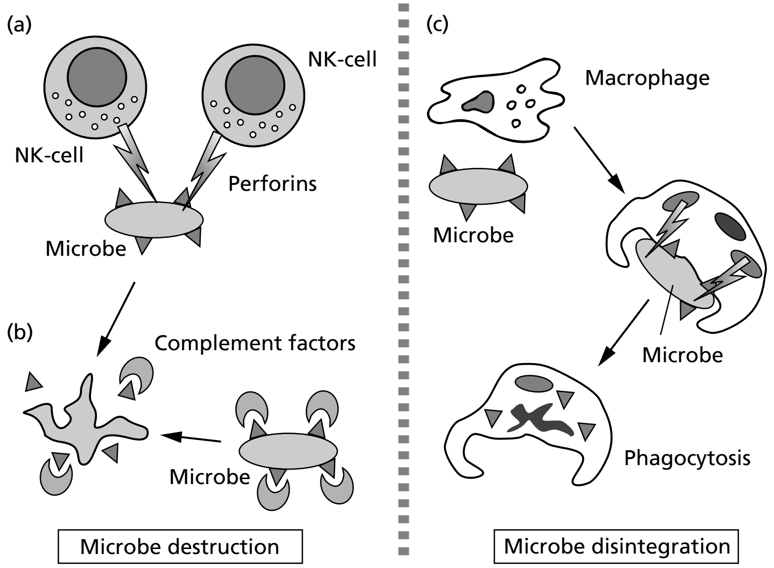

Fig. 4.4 The unspecific second line of defence is mainly characterized by three types of response to invading antigens/ microbes: (a) activated cytotoxic lymphocytes such as NK-cells which release chemicals (perforins) which punch holes in the microbial wall or release signal molecules (cytokines) which induce microbial 'suicide'; (b) complement factors (reactive proteins produced by the liver) which attach to surface antigens of the microbe and 'explode' like a grenade on the microbe; (c) activated macrophages (and neutrophils) which round up individual microbes, eat them and destroy them inside the cell with chemical agents such as oxygen radicals and lysozymes. The activation of these responses is governed by a number of signal molecules (interferons, tumour necrosis factors, lipopolysaccharides, etc.).

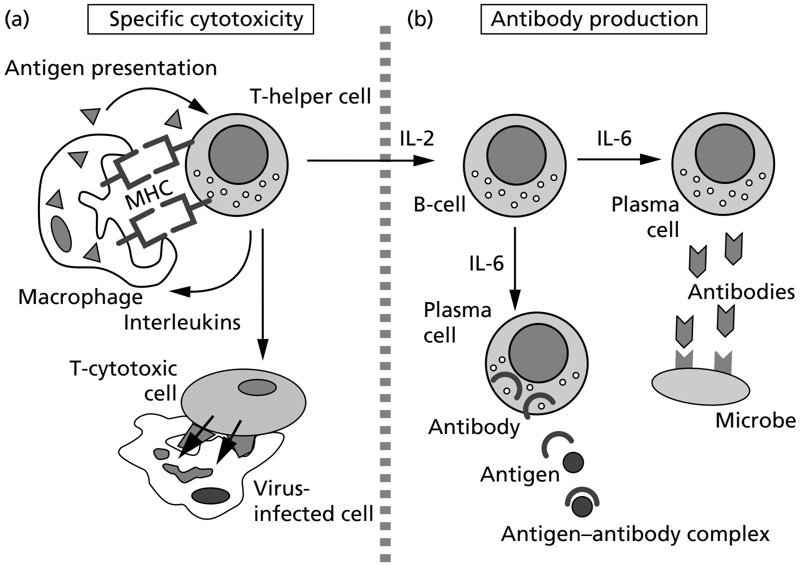

Fig. 4.5 The specific third line of defence may be activated by macrophages presenting antigens to T-helper cells by direct cell-to-cell contact mediated by special attachment molecules. Subsequently, the most appropriate immune reaction is organized by these T-helper cells, mainly involving two types of response to the invading antigens/microbes. (a) Activated T-helper cells secrete certain signal molecules called interleukins (IL-2) which stimulate the proliferation of specific T-cytotoxic cells. These cells are able to make direct contact with virus-infected cells by using a specific surface molecule which matches the surface antigen of the infected cell and then kills by injecting lethal chemical agents. (b) B-cells which pick up the antigen code from T-helper cells are stimulated by an interleukin (IL-6) to proliferate into a clone of plasma cells to produce specific antibodies. These antibodies connect to 'free-floating' invading antigens—in the same way as a specific key fits the lock—and thus initiate the elimination of the invader.

Functions of the immune system

Both the exterior protective system and the interior reactive system are parts of our total defence against invading microbes and foreign material from the environment, but it is the 'inside' system which is traditionally referred to as the immune system. Even though the physical and biochemical barriers on our skin and mucous membranes mostly offer passive protection, the components of the first line of defence are extremely important in limiting the number of antigens that our immune system has to deal with.

The basic functions of immune cells are:

- recognizing and identifying material as 'self' and 'non-self' substances;
- phagocytosis—eating of foreign ('non-self') substances (antigens);
- producing and storing chemical agents for the destruction of various antigens;
- producing 'custom-made' killer cells and antibodies against specific antigens;
- producing and secreting signalling molecules for immunological communication;
- regulating and coordinating an adequate immune response according to the antigen stimulus;
- storing specific immunological codes for all encountered substances (self and non-self).

The second line of defence consists of cells and soluble components which can discover antigens/microbes and instantly attack these, mainly by way of three unspecific strategies (Fig. 4.4). Cytotoxic lymphocytes, such as the natural killer (NK) cells, can inject the microbe or infected cell with chemicals agents, such as perforins, which punch numerous holes in the outer membrane and thereby destroy the microbe/infected cell. Another method of destruction is the use of reactive proteins called complement factors present in vast numbers in tissues and blood vessels. Upon activation, these complement factors attach to surface antigens of the microbe and 'explode' like grenades on the surface thus disintegrating the microbes (Fig. 4.4b). In the same way as macrophages and neutrophils, phagocytes surround individual microbes, engulf them and chop up the microbe into bits and pieces by use of internal chemical agents such as lysozymes and oxygen radicals. In most cases when the second line of defence is activated, a combination of all attacking strategies is used. Some cells (macrophages) also function as communication links to the third line of defence by presenting the digested antigen part to certain lymphocytes. The cells and soluble components of the second line of defence are an inborne (innate) part of the immune system and are already operative from the time of birth.

Conversely, the third line of defence (Fig. 4.5) is an acquired (adaptive) part of the immune system where the resistance to harmful antigens is developed throughout life, as new substances are encountered by the immune system every day. Some cells (T-helper cells) are specialized to identify any invading antigen by their specific surface structure (antigen code) and subsequently organize the most appropriate response against the invader (Fig. 4.5a). Others cells (B-lymphocytes) are specialized, producing specific antibodies that connect to 'free-floating' invading antigens—like a specific key fits the lock—and thus initiate the elimination of the invader (Fig. 4.5b). Still other lymphocytes (T-cytotoxic cells) connect directly to cells that contain the antigen/virus—also in a specific key and lock connection—and use their destructive chemicals to eliminate the infected cells (Fig. 4.5a). A final characteristic of the third line of defence is its ability to save the various antigen codes, thereby being able to restart antibody production instantly in the case of a subsequent encounter with the same code.

The fate of a microbe

Having briefly described how the main components of the immune system are organized, it should be easier to understand the main principles of how it works when a challenge arises. If a microbe penetrates one of the components of the outer protective system (first line of defence), e.g. the skin, a coordinated response from both the second and third line of defence immediately takes place (Fig. 4.3). This involves phagocytic cells (neutrophils, eosinophils and macrophages) and chemical agent producers (monocytes, mast cells and NK cells). The necessary 'fore-checking' of the substance against the memorized list of 'self' and 'non-self' material is quickly accomplished. However, if it is identified, for example, as a bacteria there is no further recognition of who the invader is before the cells start their attack. The phagocytic cells in the invaded tissue will

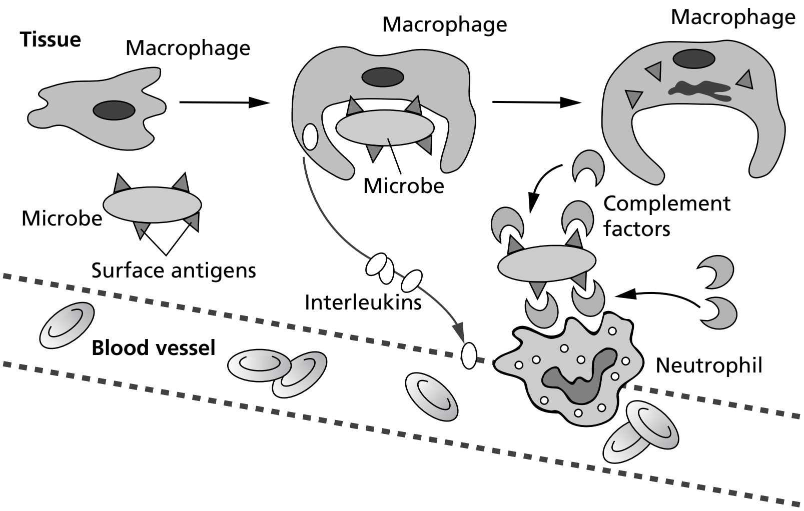

Fig. 4.6 If microbes enter the tissue through a skin wound, certain fragments of the microbes (lipopolysaccharides, LPS) activate the macrophages that start to engulf them. During this 'eating' process, the macrophage will secrete signal molecules (interleukins) to the nearby wall of a blood vessel, whereupon certain changes in the permeability of the blood vessel takes place. This enables several neutrophils to move from the blood and into the infected tissue, thereby helping the macrophages in the phagocytosis of the invading microbes. Certain soluble proteins called complement factors in the tissue can 'coat' the surface antigen molecules of the microbes and thereby make them more easily digestible for the macrophages and neutrophils.

quickly start to surround and engulf the bacteria and destroy it with reactive chemical agents (Fig. 4.6). This immune reaction may be sufficient to eliminate a few bacteria, but if several colonies of bacteria are invading the tissue extra neutrophils, macrophages, NK cells and complement factors are mobilized from the blood circulation. This is achieved by secreting specific signal molecules (interleukins) that attach to the wall of a blood vessel and facilitate the migration of neutrophils out of the vessel. However, despite this ability to recruit additional help to the infected area, the cells and soluble components of the second line of defence lack the capacity and efficiency to handle a large invasion of bacteria or viruses, not to mention pollen.

This is where the third line of defence (Fig. 4.5) comes into play and serves a vital function in handling not only larger invasions of antigens, but also pathological transformations (mutations) of the body's own cells. A prominent characteristic of this part of the immune system is that certain cells (T-lymphocytes) are able not only to distinguish between self and non-self substances, but also to identify and process the specific antigen code that exists for every chemical substance in our environment. The high efficiency and capacity to destroy large numbers of microbes are based on two main strategies.

1 The ability to make large numbers of lymphocytes (T-cytotoxic cells) with a specific surface code that fits the invading antigen, and thus destroys the microbe by direct attachment.

2 The ability to make one line of cells (B-cells and plasma cells) that produce a large number of one specific antibody molecule corresponding to the surface structure (antigen code) of the invading substance.

The first strategy is called a *cellular immune response* and the second strategy a *humoral (soluble factor) response*. The type of antigen (allergens, viruses, bacteria, fungi, protozoa, foreign substances) that comes into contact with the components of the third line of defence decides which of the two strategic reactions will be the dominant response.

When a microbe, such as the influenza virus, challenges the body, T-lymphocytes are instrumental in obtaining and deciphering the specific surface code of that particular virus. However, before any further action can be taken, a macrophage has to process and present the virus properly to specific T-helper cells (Fig. 4.5). These T-cells are involved in the transfer of the antigen code to other lymphocytes as well as signalling the rest of the immune system to organize a proper response. Subsequently, if a humoral response is initiated, the B-cell that first receives and breaks the code is vastly multiplied in exact copies of itself (cloning, Fig. 4.5b). These cells (plasma cells) are then set up to produce large numbers of a specific antibody that matches the surface structure of the virus. The last step in this immune reaction is attachment of the specific antibody to the influenza virus either as free-floating or on the surface of other cells. This strongly facilitates the ultimate destruction of the virus, which is executed by specialized killer lymphocytes (NK cells and cytotoxic T-cells).

If the invading virus is mostly hidden inside the body's own cells (like mucosa cells of the airways) a cellular immune response is the most appropriate reaction to the invading virus (Fig. 4.5a). The macrophage-activated T-helper cell will then initiate a proliferation of T-cytotoxic cells that have the same surface code as the virus-infected cell (the virus leaves 'footprints' before it enters the cell). As soon as these specific T-cytotoxic cells are made, they will be circulated to the infected tissue—including the blood compartment—attach to the infected cells, and destroy them one by one. This whole process of identifying and presenting the virus, transferring the antigen code to a B- or T-lymphocyte, cloning the correct plasma B- or cytotoxic T-cell, and finally producing a large number of specific antigens or killer cells normally takes about 4–6 days, which is why the signs and symptoms of most common viral diseases last for about a week.

Immunological memory and integration

When the third line of defence is activated in an immune response to any foreign substance, the antigen code is stored—mostly for the rest of our lives—by specific lymphocytes (memory cells). This enables the immune system to rapidly resume the production of large amounts of specific antibodies or killer cells if the same antigen should present itself again. This will limit or eliminate the harmful effects on the body of such a rendezvous and keep us from becoming ill from the same virus or microbe more than once. Over the years we therefore acquire immunity towards many common illnesses. Unfortunately, many viruses have found a way to continue the infliction of illnesses on the human body by developing the ability to alter their surface structure enough to cause a change in their characteristic antigen code. By way of this 'cosmetic surgery', the immune system does not recognize the virus as known, and even though the resemblance to the previous 'edition' of the virus is considerable, the immune system has to start all over again with the code identification, which is why vaccines (material from bacteria or virus that contain the antigen code) are ineffective against unstable surface-changing microbes. In the meantime, we become ill from yet another influenza virus.

The second and third lines of defence are not separate entities in our immune system. In most instances, when the immune system is challenged by a pathogenic microbe (causing illness), both the non-specific second 'army' and the specific third 'army' of the immune system are mobilized. A good example of the excellent cooperation between the cells of these two 'armies' is the interaction of the macrophage (second line) and the T-helper cell (third line). In a position right underneath the mucous membrane of our upper airways, macrophages will quickly engulf most viruses that penetrate the surface and present the virus with its surface code to a T-helper cell (Fig. 4.5). The activated T-cell reads the code and then delivers it to the B-cell for proper antibody production. However, the communication is reciprocal. Upon activation by the macrophage, the T-cell secretes specific signal molecules (cytokines, such as interleukins) that return to the macrophage with the message that it may now destroy the virus. Similarly, when the first T-cell has succeeded in transferring the antigen code to a B-cell, the B-cell signals back to the other T-cells that have acquired the same code and then the 'transfer race' is called off. What a masterpiece the immune system is.

Exercise stress and 'the open window' hypothesis

Activation of the immune system has so far been described in connection with presentation of various antigens. However, an immune response may arise from several other stimuli or conditions, such as increased core temperature, increased blood circulation, certain hormone disturbances, dehydration, caloric deficiencies, psychological stress and, not least, physical exercise (Fig. 4.7). The common denominator here is stress involving various physiological systems of our body. Exposure to stress activates the immune system much the same way as invading microbes and foreign substances. When taking a closer look at the different stressors that may initiate a reaction in the immune system, it is evident that physical exercise may result in all of the conditions mentioned in Fig. 4.7, depending on the

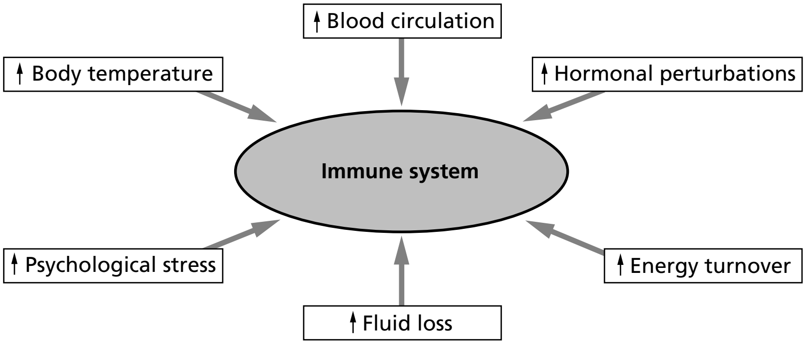

Fig. 4.7 Exposure to exercise stress activates the immune system in much the same way as invading microbes and foreign substances. This may be caused by exercise-induced increase in core temperature, increase in blood circulation, increase in stress hormone concentrations, dehydration, caloric deficiencies, psychological stress and other factors.

intensity and duration of the exercise. Mobilization of immune cells such as neutrophils into the blood circulation is one of the most characteristic immune responses to acute exercise. The large increase in neutrophils observed during a 50 km (males) and 30 km (females) cross country World Cup race is illustrated in Fig. 4.8. Not surprisingly, there is a link between both acute (single bout) and chronic exercise (repeated bouts) and the immune status of an athlete. Furthermore, it has been demonstrated that exercise can lead to both activation and suppression of certain immune functions if a single bout of exercise is prolonged and intense or if successive training sessions are repeated too frequently. In a recent study, the effects of 2 months of endurance training and competitions on the immune system of cross country skiers were evaluated using 10 competitive skiers, 10 moderately trained skiers and 10 untrained healthy controls. The data from the investigation suggest that the immune system may profit from moderate endurance training while repeated exhausting exercise may result in a deterioration of certain aspects of the immune system of competitive athletes.

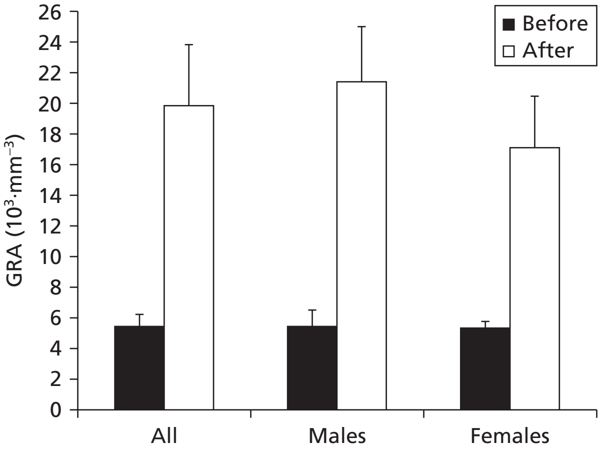

Fig. 4.8 Changes in neutrophil granulocyte concentrations from 1 h before to immediately (1 min) after a 50 km (males) and 30 km (females) classical cross country World Cup race. The fourfold increase during the race indicates a major physiological stress to the immune system.

On the basis of a few epidemiological studies on the relationship between training loads and risk of upper respiratory tract infections (URTI), the 'J-curve' hypothesis has been put forward (Fig. 4.9). This suggests that a person will reduce his or her risk of URTI if changing from a sedentary lifestyle to a moderate training schedule. However, if the training load is increased from moderate to high, the risk will increase again and more episodes of URTI than normal may be expected. Putting in heavy volumes of training in addition to races or high-intensity training, cross country skiers may find themselves in the upper right-hand corner of this graph, with recurrent respiratory infections. There is some evidence to suggest that rather than increasing the *number* of URTI episodes, high training loads will result in *prolonged* episodes of URTI. Even though clinical experience and anecdotal histories of infectious episodes in athletic teams may support this hypothesis, it is by no means well substantiated by scientific evidence yet. Part of the reason for the lack of good scientific data is the problem of controlling the variable of infection exposure in a group of people who have contact with many different individuals over a period of time (season). This is imperative in order to estimate the effect of training alone on the risk of infection.

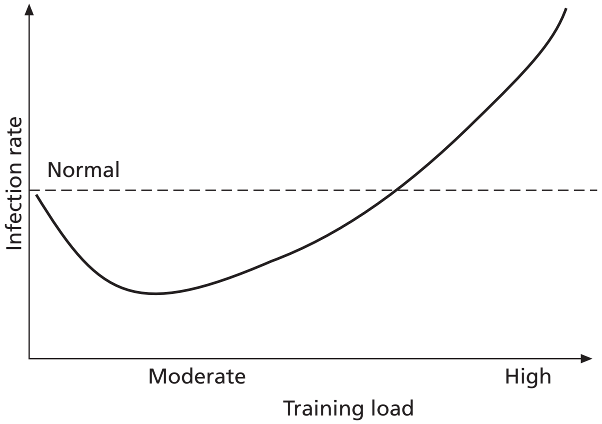

Fig. 4.9 The J-curve hypothesis. Compared to a normal frequency of upper respiratory tract infections (URTI) for a sedentary person, increasing the training load to moderate levels will decrease the number of URTI per season/year. If training load is increased further, to a relative high level, the number of URTI will increase accordingly to a higher than normal frequency.

The few studies that support the J-curve hypothesis have not measured immune parameters, and thus not established any link to possible perturbations in certain immune parameters. On the other hand, those studies that have demonstrated changes in immune parameters after prolonged strenuous exercise—suggesting immunosuppression—have not looked at possible changes in infection rates following such exercise. Therefore, this leaves an important gap of evidence when trying to establish a link between repeated bouts of strenuous exercise, subsequent immunosuppression and, ultimately, increased risk of infection (Fig. 4.10). Nevertheless, some scientists have taken 'a leap of faith' and suggested that this relationship is likely to exist. It has been named the 'open window' hypothesis. The metaphor pertains to a temporary 'opening' of the protective immune functions against invading microbes after prolonged strenuous exercise (Fig. 4.11). The low number of lymphocytes during the first 4 h after exhaustive exercise, demonstrated in one of our studies on cross country skiers, illustrates this concept of the 'open window' hypothesis. Because other signs of short-term immunosuppression have been demonstrated in several exercise studies (as indicated in Fig. 4.10), it is conceivable that an increased susceptibility to invasive microorganisms could exist during this period. However, it is likely that several hard training sessions without complete recovery must be repeated over several days or weeks before a sustained condition of immunosuppression will manifest itself. Under such circumstances, exposure to even small amounts of pathogenic microbes could result in an infectious episode.

Main points to remember about the immune system

- The immune system—with its cellular and soluble components—is dispersed throughout most of the body with connecting blood and lymph vessels as a communication web between the different immuno-active tissues (Fig. 4.1).

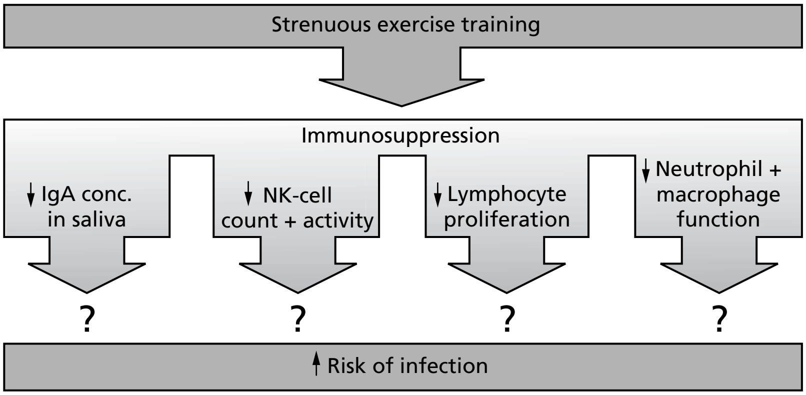

Fig. 4.10 Prolonged strenuous exercise is known to cause several changes in the immune system. Decreased concentrations of immunoglobulin A in nasal secretion and saliva, decreased NK cell counts and activity, decreased lymphocyte proliferation (activation and mitosis) and decreased killing capacity of neutrophils and macrophages are alterations that suggest a temporary state of immunosuppression after such exercise. However, a causal link from these exercise-induced perturbations in the immune system and subsequent increases in infection rates in athletes has not yet been scientifically established.

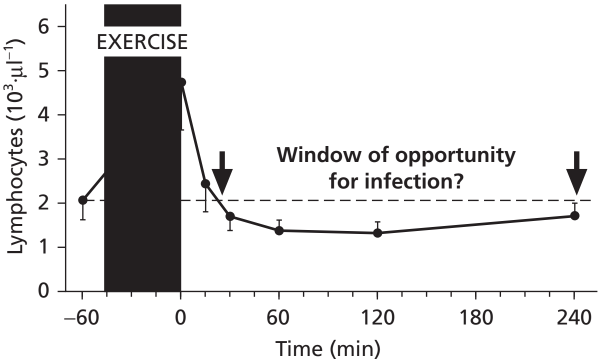

Fig. 4.11 Lymphocyte counts in the blood typically increases during exercise and decreases postexercise. If prolonged strenuous exercise is performed, the lymphocyte count will be suppressed (below baseline values) for a certain number of hours after exercise. The 'open window' hypothesis suggests that a temporary reduced resistance to invading microbes exists after prolonged strenuous exercise, and this short-term (4–8 h) 'immunosuppression' may result in increased risk of infection.

- The body's defence against foreign substances and invading microbes (antigens) is made up of an outer *protective* system (physical and chemical barriers and secretory material) that constitutes a first line of defence; and an inside *reactive* system (immune cells and soluble components) that constitutes a second and third line of defence (Fig. 4.3).
- The first line of defence with the physical and chemical barriers on our skin and mucous membranes offers mostly passive protection, but is very important in limiting the number of antigens that the immune system has to deal with.
- The second line of defence consists of cells that identify foreign antigens/microbes and instantly attack these by way of phagocytosis (engulfing of the microbe) or chemical components (enzymes, complement factors, oxygen radicals) that penetrate and destroy the antigen/microbe (Fig. 4.5a). This is an unspecific immune response.
- The third line of defence is organized by T-helper cells, which are specialized in identifying invading antigens by their specific surface structure (antigen code) and subsequently coordinate a specific immune response. This includes B-cell proliferation with production of specific antibodies that connect to the invading antigen, and/or proliferation of specific T-cytotoxic cells that connect directly to foreign/infected cells (Fig. 4.5a).
- The unspecific immune response is quickly activated (1–3 h), but can handle only a limited number of invading microbes; while the specific immune response takes 4–6 days, but has large capacity and is highly efficient.
- When a specific immune response is activated by a virus, the antigen code is stored by specific lymphocytes (memory cells). This enables the immune system to rapidly resume the production of large amounts of specific antibodies or killer cells if a person is exposed to the same virus again, and illness is thus avoided.
- Exposure to stress—and, in particular, strenuous exercise—is a potent stimuli for the immune system, which may result in both activation and depression of several immune functions (Fig. 4.7).
- The 'J-curve' hypothesis suggests that a person will reduce his or her risk of URTI if changing from a sedentary lifestyle to a moderate training schedule; however, if the training load is increased from moderate to high, the risk of infections will rise to above normal frequency (Fig. 4.9).
- The 'open window' hypothesis suggests that a temporary reduced resistance to invading microbes exists after prolonged strenuous exercise, and this short-term (4–8 h) 'immunosuppression' may result in increased risk of infections (Fig. 4.11).
- Key factors for reducing risk of infection in athletes includes:
  1. reduced exposure to people and places with microbes;
  2. reduced overall life stress;
  3. reduced stress to respiratory mucosa (cold air, allergens and dehydration);
  4. proper outdoor clothing;
  5. improved recovery routines;
  6. optimizing nutritional status, including vitamins and minerals.
- There may be a role for low dose (400–800 mg·day^{-1}) vitamin C supplementation in endurance athletes, particularly during altitude training and the winter season, but recommendations for other nutritional supplements are not presently warranted.

Prevention of infections in cross country skiers

The most common infections

In endurance sports such as cross country skiing, respiratory tract infections (RTI) are the most common cause of missed days of training and competitions. Respiratory tract infections include infectious illnesses to both upper (URTI) and lower respiratory tract (LRTI), above and below the vocal cords, respectively. The reason for the separation into the upper and lower respiratory tracts at the vocal cords is that below this anatomical area the airways are sterile (no presence of microbes), while above the vocal cords some microbes are tolerated on the mucous membranes without resulting in illnesses (non-pathogenic microbes). Most infections among athletes are in the upper airways and may involve several anatomical areas. An infection in a specific region of the airways has its own name based on Latin terminology.

Upper respiratory tract infections
Rhinitis—infection of the nose
Sinusitis—infection of the sinuses
Pharyngitis—infection of the throat
Tonsillitis—infection of the tonsils
Laryngitis—infection of the vocal cords

Lower respiratory tract infections
Tracheitis—infection of the trachea
Bronchitis—infection of the bronchi
Pneumonia—infection of the lungs

Infections to the respiratory tract may be caused by any microbe passed on from contagious sources in the external environment or from a reservoir of microbes in/on our own bodies. Most frequently, RTI are viral infections that appear as 'common colds' with the well-known symptoms of sore throat, nasal congestion, and feeling of malaise and fatigue. However, not so uncommonly, bacterial infections appear during or after the initial viral episode, causing an extended period of illness. In some instances, bacteria-like streptococci and pneumococci may be the primary cause of infection, as is often the case in tonsillitis. Fungal infections to the upper airways may occasionally occur, most often as a consequence of extended use of inhaled corticosteroids for the treatment of asthma or use of certain antibiotics.

Gastrointestinal infections and urogenital infections are also encountered in the athletic community. However, instead of reviewing the signs, symptoms, diagnostic criteria and treatment of common infections already published in medical textbooks this section focuses on how to prevent or minimize the risk for such episodes.

As RTIs are the most commonly encountered illness in athletes, the following text focuses mostly on these. However, preventive measures towards RTIs are shared with many 'non-respiratory tract' infections, and may therefore be applicable in cases of other types of infections affecting the urogenital or gastrointestinal tracts. Most respiratory infections appear during the winter season, partly because of climatic changes, but also because people spend more time indoors in closer contact with each other. Even though most of these RTIs do not inflict serious illness, the mere fact that upper airway and/or pulmonary function is affected may easily compromise the performance of a cross country skier. Additionally, several skiers have had the unfortunate experience of imposing more chronic airway diseases such as asthma and bronchial hyperreactivity on themselves, because an episode of RTI was not properly recognized or healed before resuming strenuous training or entering a cross country ski race. Therefore, preventing or minimizing the risk for these infections is one of the most important tasks for the team physician and medical staff.

There is no method or measure that completely eliminates the risk of catching an RTI, but there is some room for *decreasing* the number of episodes of most infectious illnesses—both on an individual basis and within the team. Besides, even when an RTI does occur, there is considerable potential for reducing the severity and complications of the illness if both the athlete and the medical staff are able to handle it correctly. Again, there is no scientifically based formula on how to prevent infectious episodes or how to treat them if they do occur. Therefore, the information and guidelines given below are primarily common sense principles and 'to the best of our knowledge' advice but, if these principles are implemented, the problems with respiratory illnesses in a team will be reduced.

Guidelines on how to stay healthy and prevent RTIs are based on the following fundamental principles.

1 Make sure that you are up-to-date on all vaccines needed at home and for travelling.
2 Minimize contacts with contagious people, places and objects.
3 Practise good standards of hygiene, both personally and for the whole team.
4 Optimize nutritional status (carbohydrates, vitamins, minerals, fatty acids, etc.)
5 Practise optimal recovery and wear proper outdoor clothing (as outlined in separate section).

6 Do not train when you are sick.

These principles address the issue of how athletes can best *avoid* an infection, but also how they can keep up an effective defence system (immune system) that *fights* invading microbes.

Vaccines

Athletes from countries with a national immunization programme have usually received vaccines against diphtheria, poliomyelitis, tuberculosis, tetanus, measles (rubeola and rubella), mumps (parotitis) and chicken pox (varicella). However, vaccines against cholera, yellow fever, hepatitis A and B, typhoid fever, and proper malaria prophylactic medication must also be considered if longer or frequent visits are made to endemic or epidemic parts of the world. The most exotic and remote destinations might require even more specialized vaccines or special travel medications. Additionally, a new oral vaccine against cholera also gives protection against some of the more common *Escherichia coli* bacteria that cause travel diarrhoea. The vaccine has been shown to reduce the risk of these episodes by 30–40% over a 6-month period.

However, before deciding on a trip to areas of the world with a different microbial flora and range of illnesses one should thoroughly evaluate the actual need for going to that particular place. Moreover, special conditions, such as previous history of travel illnesses and temporary signs of immunosuppression, need to be considered. It is most important that both risks and benefits of going to a foreign destination have been discussed among the medical and coaching staff as well as with the athletes. Whether travelling privately or as a member of the ski team, before the trip starts one should always inquire of the local or national health care authorities to ensure that the individual immunization status is adequate and all necessary prophylactic measures have been taken. Several vaccines have a limited period of effective coverage; booster doses should therefore be given at certain intervals after initial immunization.

Fig. 4.12 A full vaccination programme according to national standards should be secured in all athletes. This includes updates on certain vaccines where there are time limitations. Then, depending on the extent and destination of particular travels, additional vaccines should be considered.

For further information on travel medicine issues, contact any of the following agencies:

1 Travel Health Online at http://www.tripprep.com/
2 The International Society of Travel Medicine at http://www.istm.org/general.html
3 The World Health Organization's Diseases Surveillance and Control publish weekly epidemiological records at {http://www.who.int/wer/}
4 Health advice for travellers at {http://www.who.int/ith/} provides updated information about changes in worldwide communicable diseases and adequate vaccines and medications.

With every winter season there is an increased risk of catching a specific influenza virus which causes generalized illness with symptoms lasting for 1–2 weeks. Everyone that has had one of these viral infections knows it is more than the common cold and it may cause complications such as sinusitis, bronchitis or pneumonia. During the autumn and early winter, vaccines against these seasonal influenzas are now usually available and every team physician has to make an evaluation of its usefulness for the team members. Even though these viruses do not strike as hard every winter (variation in virulence), and there are seldom risks for serious illness in healthy athletes, they do cause a minimum of 10–14 days out of regular training and may hit very inconveniently during championships or major competitions. The close contact between all members of the team during the winter season increases the contagiousness of the virus when it hits a team member. Therefore, if one decides to use the vaccine, not only athletes but all members of the team should be asked to take it.

Contagious sources and hygiene guidelines

Although vaccines cannot guarantee 100% resistance against specific diseases, they are by far the most effective way of preventing certain infections. However, there are a number of microorganisms (viruses, fungi, bacteria, algae and protozoa) that may cause a host of infectious diseases for which there are no effective vaccines. To minimize the risk of contracting any of these infections, it is very important to avoid unnecessary contact with contagious sources. However, in order to do this, the athletes and other team members first have to be able to recognize the potential contagious sources of the most common infectious diseases.

1 Infected people and animals:
   - skin/hands, hair, open wounds, mucous secretions, blood, semen, urine, faeces.

2 Infected materials and objects:
   - glasses, silverware, bottles, towels, handkerchiefs,
   - doorknobs, floors, pools, ventilation systems, etc.

3 Food and drinks:
   - raw meat and eggs, unboiled seafood, old salads, etc.
   - contaminated tap water, ice-cubes, sports drinks, etc.

From this list, a number of 'beware of . . .' and 'do not . . .' may be created. However, differences in geographical location, sanitary equipment, housing standards and local routines of hygiene require individual evaluations of the risk of being infected by contagious material. Educating the athletes and other team members on the most common sources of infection in their environment should result in behaviour changes both at home and when travelling with the team. As an example, it should make the athlete more restrictive in contact with sick children and people in their home setting—particularly during the week before joining the team for training camps and travelling to competitions. Another change in behaviour could be a more careful routine of handwashing after shaking hands with people who may be contagious.

It is important to emphasize that contagious material is both *received* by and *passed on* from any individual. This means that one should pay as much attention to routines that prevent the transmission *from oneself* to others as *from others* to oneself. The golden rule of practising the same standard of hygiene when in contact with others as you expect others to practise towards you should be an overall objective. Countermeasures against three common ways of transmitting contagious material—through air, direct contact and food/drinks—are listed below.

Countermeasures against air transmitted infections

1 Keep your distance from people who are coughing, sneezing or who have a runny nose.

2 Quickly isolate a team member getting sick—as well as his or her room-mate.

3 Keep your own coughing and sneezing away from your hands and other people.

4 Wash hands regularly, before all meals and after contact with mouth and nose (Fig. 4.13).

5 Use disposable paper towels and limit hand to mouth/nose contact.

6 Check ventilation/air conditioning systems and hotel air humidifiers.

7 Keep dust off floors and furniture.

Fig. 4.13 Proper hygiene of hands may be one of the most important preventive measures against infectious diseases in athletes. Washing hands before each meal and after visits to the bathroom are obligatory, and considered a benefit to oneself and the other athletes on the team.

Countermeasures against direct contact transmitted infections

1 Use gloves when in contact with (potentially) infectious material.
2 Wash hands after unintentional contact with potentially infectious material.
3 Rinse and cover up secreting wounds and skin lesions.
4 Do not use other people's used exercise clothes or towels directly on your body.
5 Use a condom when having sex with a new partner.
6 Quickly isolate persons if sudden vomiting and diarrhoea should occur.

Countermeasures against food and fluid transmitted infections

1 Check the kitchen hygiene and tap water in new hotels and restaurants.
2 Do not eat raw or rare meat, seafood and eggs.
3 Stay away from reheated food and buffet food that has been out too long.
4 Rinse vegetables and peel fruits.
5 Use bottled water if questionable water quality.
6 Do not use other people's water or sports drink bottle.
7 Avoid swallowing water when in fresh water, pools, or hot tubs.

The relevance and importance of these—as well as other advice on actions to minimize the risk of infections—must be evaluated against the changing circumstances and locations that the team are subjected to during a season. The team physician or other medical staff should preferably review these measures both ahead of travel and as soon as possible upon arrival to a new location through a briefing with the team. By choosing identical locations and hotels for training camps and competitions from one year to another, part of this process becomes easier.

Furthermore, in a travelling cross country team, where all members have vital functions and are in close contact with each other, it is very important that all members follow the same routines. When trying to prevent contagious diseases the effectiveness of the preventive measures is never stronger than the weakest link. So, if the physician or a waxer is mingling with sick or contagious people outside the team during a championship, and disregards some of the hygiene rules, the result could be transmission of an infectious disease into the team. Needless to say, the consequences of such carelessness may be devastating for some of the athletes. However, it must be emphasized that it is a challenge for the medical staff to balance the preventive measures against infectious episodes with the quality of life and well-being of the team, so that these routines do not impose unnecessary and unwanted restrictions on individuals.

Nutritional modulation of immune status

Athletes involved in heavy training may experience a state of temporary immunosuppression, but this is likely to be multifactorial in origin. Undoubtedly, improper nutrition is one of the factors that may contribute to increased risk of illness during periods of intensive training and competitions. However, even though proper nutrition can counteract some of the negative influence of heavy exertion on immunocompetence, it is not a situation where higher than normal doses of vitamins and minerals will generate a stronger than normal immune system. Based on the importance of several metabolically active substances in immune cells, supplements of antioxidant vitamins C and E, the amino acid glutamine, polyunsaturated fatty acids (PUFA), antioxidant minerals selenium and zinc, and several other chemical compounds have been suggested as candidates for alleviating suppression of the immune system in connection with strenuous exercise.

Regarding nutritional supplements and risk of infections in humans, only vitamin C in supplementary doses of 400–800 $\mathrm{mg \cdot day^{-1}}$ has proved effective in reducing the incidence of URTI. This has only been documented in a couple of studies where vitamin C was given 2–3 weeks prior to ultra-marathon races and symptoms of infections were monitored over 2 weeks after the race. Other investigations using endurance athletes have not shown this reduced risk of URTI with vitamin C supplementation. Furthermore, unless deficiency of vitamin C has been evident, no human studies have shown that supplementation can affect clinically relevant immune parameters suppressed by prolonged strenuous exercise. Nevertheless, a metaanalysis of studies on vitamin C and common cold episodes in people under heavy physical stress shows a reduced incidence among those who supplemented 0.5–1.0 g·day^{-1} of vitamin C. Thus, there may be a role for low-dose vitamin C supplementation in endurance athletes, particularly during the winter season with its increased rates of respiratory infections.

Vitamin E has a central role in several functions of the immune system and even a marginal deficiency may impair important parts of an immune response. Nevertheless, being a fat-soluble substance, vitamin E deficiency is rare in nutritionally balanced athletes. Supplementation of vitamin E has been shown to reduce the spread of influenza virus in stressed mice but its role in humans, and athletes in particular, is not clear. In older people with age-induced alterations in immunocompetence, vitamin E supplementation seems to improve both humoral and cell-mediated immunity. However, a general recommendation for supplementation of vitamin E in reducing exercise-induced immunosuppression cannot be given at this point, and further clinical studies including elite athletes are strongly warranted. The situation is much the same for the role of PUFAs in reducing exercise-induced imbalances in the immune system and infection risk. The relevance for specific PUFA supplementation is based on the potential of reducing prostaglandin-mediated inflammation and suppression of immune cell functions. Increasing the ratio of ω-3 : ω-6 PUFAs by supplementary intake of ω-3-rich fish oils has been demonstrated to reduce the production of prostaglandin E2 and other markers of inflammation. Furthermore, parameters indicating suppressed immune function, such as reduced NK cell activity, are also associated with high intake of ω-6 in the form of linoleic acids. Thus, the balance between ω-3 and ω-6 fatty acids seems to affect certain aspects of inflammation and immune function. Again, most of the data come from animal experiments and clinically relevant measurements of immune responses and infection rates in humans are not available to substantiate recommendations for PUFA supplementation for athletes. Nevertheless, for several aspects of general health, including cardiovascular functions, foods and supplements rich in ω-3 fish oils may be advantageous and should therefore be considered by athletes.

Glutamine has received special attention with regard to states of exercise-induced immunosuppression because it is a vital nutrient for activated lymphocytes. Optimal proliferation of lymphocytes as part of a cellular immune response is dependent on glutamine being available inside the cell. A decrease in plasma levels of glutamine has been found in connection with strenuous exercise and marathon races where lymphocyte function is compromised. However, a causal relationship between glutamine concentrations and lymphocyte function is not evident unless glutamine levels become extremely low, far below that measured in exhausted athletes. Therefore, most investigations have failed to demonstrate beneficial effects of glutamine supplementation on immune functions, including those most suppressed by exercise. Apart from the contribution toward rapid restoration of protein balance after heavy exertions, glutamine supplementation does not seem to have significant immunomodulating effects or reduce the frequency of infectious episodes in athletes.

The commonly used carbohydrate (CHO) supplements in sports drinks have been shown to reduce exercise-induced changes in hormones, cytokines and phagocyte functions involved in regulating several immune responses. Attenuation of exercise-induced elevations in stress hormones such as cortisol and growth hormone, pro-inflammatory cytokines such as interleukin-6, and microbial killing capacity of macrophages have been demonstrated after marathon running when CHO drinks were used compared to water. The fact that CHO drinks reduce the peak concentrations of several signal and effector molecules involved in immune responses during and after strenuous exercise indicate that such supplementation alleviates exercise-induced stress on the immune system. Again, it remains to be shown that this has clinical relevance in the form of reduced frequency of infectious episodes.

Recovery routines

As exercise of above a certain intensity and duration is known to impose a stress on the immune system, good recovery regimes after each training session are vital in re-establishing a balance in the immune system as fast and completely as possible. To accomplish effective stress balance after training each athlete has to consider several aspects of stress management in their lives. This may include plenty of rest and sleep, proper rehydration and dietary habits, effective musculoskeletal relaxation, active psychological and social strategies to 'detach' the sports-focused mind, etc. The reader is recommended to review the practical recommendations for effective recovery, which is covered in Chapter 5.

The principal lesson to keep in mind is that our immune system is a stress-responsive system that may be diverted from dealing effectively with infective microbes if overstressed by non-infective challenges such as strenuous exercise or hefty life stress. After strenuous exercise of 1 h or more, several signs of immunosuppression have been demonstrated. The magnitude and duration of these immunosuppressive changes are related to both the intensity and duration of the exercise, and thus a period of susceptibility to microbial invasion may be created. The 'open window of opportunity' for viruses and bacteria to infect an athlete during the first hours after strenuous exercise may be kept to a minimum if the immune disturbances are normalized quickly. A good example of how a certain recovery measure may decrease exercise-induced disturbances in the immune system is the use of sports drinks containing carbohydrates. However, it must be emphasized that if the athletes are meticulous in their daily routines during and immediately after training sessions, the chances of contracting an infectious illness when exposed to various microbes is considerably reduced. For example, when athletes consume sports drinks containing carbohydrates instead of plain water during and after their training sessions, the immuno-endocrine stress response in the body is attenuated and thus the immunosuppressive effects of strenuous exercise are reduced. Ultimately, this may in turn lead to a decreased risk of infections, and athletes should therefore consider sports drinks or other carbohydrate solutions as an important supplement to their recovery regime.

Fig. 4.14 Changing clothes immediately after a race or hard workout is an important measure in preventing excessive body cooling. If outside, wet clothes should be exchanged with dry clothes while the body is still warm. This may reduce the risk of respiratory infections in athletes during the winter season.

A brief reminder of the importance of proper outdoor clothing is also appropriate when going through some of the main strategies for reducing the risk of infections in athletes. The two main principles regarding the impact of clothing in preventing unnecessary infectious episodes are: (a) staying warm and (b) staying dry. Cross country skiers probably know more about this than any other athlete. Almost every skier has experienced how improper thin clothing or the lack of dry clothing can result in subsequent infectious episodes. In addition to recommending warm but heat-transmitting and wind-breaking clothing for outdoor training, a message to take home must be the importance of having dry clothing available immediately after training sessions or competitions have ended (Fig. 4.14).

Finally, the significance of limiting the exposure of cold air directly on the inner surface (mucosa) of the airways must be highlighted. This is discussed further in the following section on asthma, but substantial evidence points to the negative effects of cooling and drying of the mucosa and decreased local resistance to infections in the airways. Because cross country skiers are often training and competing in a cold climate, this exposure may become a major health concern if not appropriately controlled. The primary preventive measure is to avoid training in particularly cold weather. However, cold tolerance is individual and training in temperatures of –10 to 15°C may be harmful to some skiers. Several devices designed to increase the humidity and temperature of the inspired air have been manufactured and used by cross country skiers and 'flipped up' jacket collars have also served the purpose of recirculating expired warm humid air. No matter what type of device or technique, the protection from dry cold air is paramount for the prevention of respiratory tract illnesses during a long career as a cross country skier.

Respiratory tract infections and training

One of the most frequent tasks for the team physician in a cross country ski team is the evaluation of training schedule adjustments and restrictions in connection with signs and symptoms of RTIs among athletes. Definite decisions and guidelines are difficult to make because the risk of both increased severity of the illness as well as sustained complications such as asthma, must be balanced with the athlete's need for good training preparation. This puts an athlete in a difficult situation that needs to be handled correctly. It puts responsibility on the athlete as much as on the physician, and a correct 'return to play' regime requires frequent consultations and good cooperation between all parties—the athlete, medical staff and coaches. Accessibility and a teamwork approach are two important principles for the team physician in this process (Fig. 4.15).

Below are some recommendations to use as guidance for the athlete and coaching staff when encountering illness during periods of training. The relevance and applicability of these recommendations must be evaluated for each episode and individual, and the team physician or another doctor should be consulted if uncertainties arise.

Illness phase

- No exercise if fever (rectal temperature >38.0°C), malaise, fatigue or other generalized symptoms such as shivering, headache and body ache, muscle and joint pain, etc., appear.
- Exercise max 60 min inside, by yourself, with pulse < 120, if only local respiratory symptoms such as runny nose, sore throat, light cough, etc.
- Drink plenty of fluids, rest inside, use NaCl spray if nose congested.
- No exercise the next day if fever and generalized symptoms persists or if local symptoms increase.
- Light alternative exercise inside, by yourself, if local symptoms persist.
- If no improvement after 3 days, consult your team or personal physician.

Fig. 4.15 When athletes present symptoms of infection on the morning of a race day, a thorough medical evaluation, sometimes including blood tests, must be carried out before a decision on racing can be made. Entering a cross country competition with an ongoing respiratory infection may cause long-term problems of bronchial hyperreactivity and may also lead to a dangerous infection of the heart muscle (myocarditis).

Convalescent phase

- Have one day without fever and systemic symptoms before resuming light exercise.
- Use approximately the same number of days for adjusted exercise as you have had symptoms before strenuous exercise or competition is resumed.
- Observe and respect your body's reaction to each bout of exercise and rest the following day if local respiratory or generalized symptoms reappear.
- Consult your physician if this strategy of return to normal training fails and your health or performance is compromised.

Once again, it must be emphasized that these are general guidelines—mostly aimed at RTIs—and should never be substituted for or used against the advice and recommendation of any physician. Nevertheless, these guidelines may prove helpful for athletes, coaches and new medical staff when handling illnesses that often occur during critical periods of serious training preparations and competitions.

Main points to remember about prevention of infections

- In endurance sports such as cross country skiing, RTIs are the most common illnesses encountered and the most common cause for missed days of training and competitions.
- Most frequently, RTIs are viral infections that appear as 'common colds' with the well-known symptoms of sore throat, nasal congestion, and feeling of malaise and fatigue.
- The immune system is challenged by strenuous exercise and to stay healthy athletes need to minimize their exposure to pathogenic microbes and maintain an optimally working immune system.
- Fundamental principles for the prevention of infections include:
  1. proper vaccines for home and when travelling;
  2. minimized contact with contagious people and objects;
  3. good standards of hygiene;
  4. sufficient nutritional intake;
  5. optimal recovery routines including minimized cold stress; and
  6. no training when sick.
- Team medical staff should ensure that all athletes have a proper immunization status and consult travel medicine authorities for the need for additional vaccination and prophylactic measures prior to travelling to destinations with a different illness panorama.
- To minimize the risk of contracting most infections, it is important to avoid unnecessary contact with potentially contagious people, objects, foods and drinks.
- Differences in geographical location, sanitary equipment, housing standards, local routines of hygiene, etc. require individual evaluations of the risk of being infected by contagious material when travelling to foreign destinations.
- Everyone in a sports team should pay as much attention to routines that prevent the transmission of microbes *from oneself* to others, as from *others* to oneself. The golden rule of practising the same standard of hygiene when in contact with others as you expect others to practise towards you should be an overall objective.
- Good routines of hygiene should include proper countermeasures against:
  1. air transmitted infections;
  2. direct contact transmitted infections; and
  3. food and fluid transmitted infections.
- Proper nutrition may counteract some of the negative influence of heavy exertion on the immune system and additional intake of 400–800 mg vitamin C·day^{-1} may reduce the risk of respiratory infections.
- General guidelines for handling infectious illnesses in athletes include:
  1. no exercise if fever (rectal temperature >38.0°C), malaise, fatigue or other generalized symptoms such as shivering, headache and body ache, muscle and joint pain, etc. appear;
  2. moderate exercise of max 60 min inside, by yourself, if only local respiratory symptoms such as runny nose, sore throat, light cough are present;
  3. if no improvement after 3 days, consult your team or personal physician;
  4. have 1 day without fever and systemic symptoms before resuming light exercise; and
  5. observe and respect your body's reaction to each bout of exercise and rest the following day if local respiratory or generalized symptoms reappear.
- These guidelines—which are mostly aimed at RTIs—should never be substituted for or used against recommendations by any physician.

Exercise-induced asthma

Epidemiology: how big is the problem?

Exercise-induced asthma (EIA) is characterized by episodes of wheezing, coughing or other respiratory symptoms and decreased pulmonary function in connection with physical exercise. Various figures for the prevalence of asthma in cross country skiers have been published. In two studies among Norwegian and Swedish elite and national-level cross country skiers in the early 1990s, 14 and 15% of the athletes, compared to 5 and 6% of controls, reported asthma-related symptoms. In another study on young national-level skiers, 46% of Norwegian and 51% of Swedish skiers reported asthma-related symptoms, However, after clinical evaluation and metacholine tests were performed, 14% of the Norwegians and 43% of the Swedes were diagnosed with EIA.

Among the Norwegian skiers the prevalence was higher in the older compared to the younger skiers, indicating an increased risk of developing asthma with the number of years that the skier is actively competing on a national and international level. Among the US cross country skiers competing in the 1998 Olympic Winter Games, 50% were found to meet the testing criteria for EIA (≥ 10% reduction in forced expiratory volume after 1 s, FEV_1). This prevalence was twice as high as for the rest of the 1998 US Olympic competitors. Physician-diagnosed asthma was found in 17% of Finnish long distance runners, but in only in 8% of speed and power athletes. Thus, it may be that both elite endurance sports and outdoors exercise during winter are separate risk factors for the development of asthma. It is beyond any doubt that bronchial hyperreactivity and asthma are problems of considerable magnitude among cross country skiers. Skiers often retrospectively report a particular episode—like a competition in cold weather (– 15–20°C)—as the precipitating incident to their asthmatic illness. Others have experienced a more gradual onset of symptoms. In both cases, a reduced performance level combined with unfamiliar breathing problems was the initial sign and symptom of EIA.

Symptoms and mechanism of exercise-induced asthma

Symptoms of asthma may vary in character and magnitude from one individual to another and both the common and more subtle symptoms are listed below.

Common symptoms of exercise-induced asthma
- Coughing
- Wheezing
- Excess mucus/sputum production
- Shortness of breath
- Chest tightness

Subtle symptoms of exercise-induced asthma
- Feeling of fatigue or ‘out of condition’
- Abdominal pain or discomfort
- Chest pain or discomfort
- Frequent colds

However, the common denominator for EIA is that these problems are triggered or aggravated by exercise and ultimately result in reduced respiratory capacity and performance. Exercise-induced asthma may occur fairly consistently even at moderate intensities: it may only happen during strenuous exercise; it may only appear in cold climate; or it may only appear in connection with respiratory infections. There are several factors that usually contribute to EIA.

Factors contributing to exercise-induced asthma
- High intensity of exercise
- Exposure to cold dry air
- Respiratory infections
- Allergens and dust
- Air irritants and pollution
- Fatigue and stress

Asthma, including EIA, is considered a chronic inflammatory disease of the bronchial mucosa and involves secretion of histamine and other mediator substances as well as triggering of the parasympathetic nervous system. There is evidence to suggest that the main mechanism involved in EIA is drying and cooling of the airway mucosa which then causes increased osmolarity in the lining cells of the bronchi. This results in activation of adenyl cyclase and subsequent secretion of preformed histamine and other signal substances. These mediators—as well as parasympathetic nerves—affect the smooth muscle cells that surround the airways, resulting in contraction of smooth muscle tissue. Consequently, a decreased dimension (radius) of the individual airways occurs and thus reduces airflow through the bronchi. It is mostly the outward flow of air (expiration) that is impaired and a characteristic prolonged expiration phase is therefore observed —often heard as wheezing. Because local water loss (drying) and heat loss (cooling) are the initial events in this cascade of reactions leading to bronchial hyperreactivity and asthma, it is obvious why cross country skiers may be particularly susceptible to these respiratory conditions. Exposure to cold air causes both cooling and drying of the mucosal lining of the bronchial airways. When large volumes of cold and dry air is breathed several hours per day, it is not difficult to understand how this can initiate irritation and inflammation of the airways and, ultimately, symptoms of asthma in many skiers. Recent research has documented inflammatory changes in the bronchial airways of both non-asthmatic and asthmatic elite skiers, but signs of inflammation were more extensive in the asthmatic skiers. This may explain why there is an increased risk of developing bronchial hyperreactivity and asthma in competitive cross country skiers. Nevertheless, genetic pre-disposition may determine who will end up with the signs and symptoms characteristic of the exercise-induced asthma illness.

Diagnostic criteria

The diagnosis of EIA is based on both a history of asthma symptoms associated with exercise and

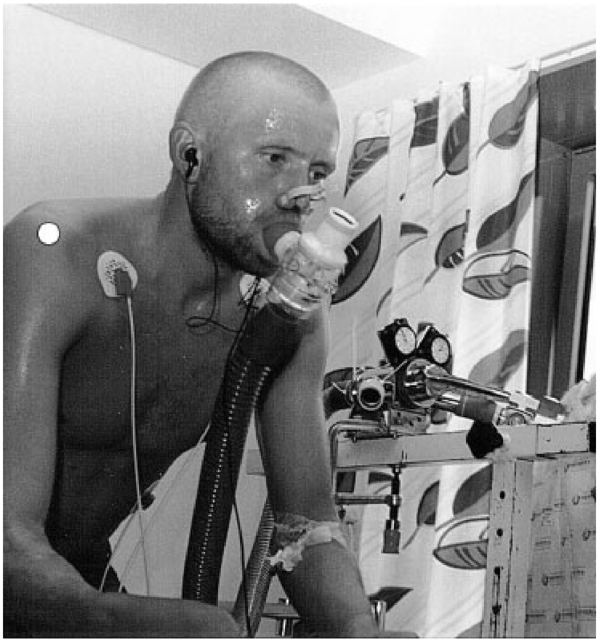

Fig. 4.16 Diagnosing exercise-induced asthma involves testing the athlete while exercising in a laboratory and measuring various parameters of lung function. In some cases the breathing problems only seem to arise in cold weather, adding cold air to the athletes airways while exercising may be necessary in order to detect an asthmatic condition.

decreased measures of pulmonary function evaluated by dynamic spirometry during and after a standardized exercise test. In sports medicine, a minimum of 10% reduction in FEV_1 or peak expiratory flow (PEF) and a partial or complete reversibility of this reduction by β_2-agonists are used as objective criteria for the EIA diagnosis. Prior to such a test, the athlete must avoid use of β_2-agonists for the last 8 h with short-acting agents and 72 h with long-acting agents and the use of corticosteroids and leukotriene inhibitors in the last 72 h.

The basic testing routine is to have the athlete rest for 5–10 min before carrying out the baseline pre-exercise test, then perform a 5–7 min exhaustive bout of exercise (min 80% of max heart rate), followed by pulmonary retesting at 1, 5, 10, 15 and 30 min postexercise (Fig. 4.16). If exercise is not sufficient to provoke a significant decrease in pulmonary function tests and a history of cold-induced symptoms is still evident, the test should be performed with adding cold air in the inspired air in the laboratory or performed as a field test during wintertime. Alternatively, direct bronchial hyperresponsiveness may be measured using a metacholine challenge test in the laboratory with the athlete breathing increasing doses of this airway irritant until a significant reduction in respiratory functions appears. A subsequent reversibility test should also be performed after metacholine exposure.

Within the last few years, a respiratory condition named vocal cord dysfunction has been discovered. This illness is characterized by explicit inspiratory and expiratory sounds from the upper airways during maximal exercise and is caused by dysfunctional air flow around the vocal cords. This condition may be a result of weakness and partial collapse of the laryngeal wall. It is easily confused with EIA because a respiratory stridor (heaviness of breathing) and particular sounds are evident, but a selective expiratory stridor—as in asthma—is seldom observed. Athletes with a vocal cord dysfunction do not respond positively to β_2-agonists; nevertheless, ipratropium bromide may alleviate some of the symptoms. This condition needs to be diagnosed by a specialist and may be successfully treated by surgery.

Treatment and prevention

Once the diagnosis of asthma has been established, several treatment strategies may be used in alleviating the respiratory problems. It is beyond the scope of this short summary to go into details on this issue, particularly regarding the numerous pharmacological treatment options. Nevertheless, listed below are some important non-pharmacological countermeasures for the prevention of recurring episodes of EIA. These routines are also important primary preventive measures for those cross country skiers who so far have not been diagnosed with asthma. All cross country skiers and other athletes exercising outdoors should therefore practise these routines in order to avoid the development of a chronic airway disease such as asthma.

Non-pharmacological/preventive measures against exercise-induced asthma

Avoid outdoor training during and immediately after respiratory infection.

Avoid any endurance exercise in very cold weather < – 15–20°C.
Only low–moderate intensity exercise if < – 10–15°C.
Use face mask or hoods with heat exchangers during exercise if < – 5–15°C.
Be well hydrated and use frequent warm drinks during cold weather.
Get inside as soon as possible after having completed skiing.
Avoid training in areas that are strongly air polluted.
Practise gradual and long warm-up routines before strenuous exercise or competitions.
Try to keep on exercising a short while at low intensity if EIA symptoms appear.

These guidelines are essential in limiting or preventing respiratory illnesses. If one particular piece of advice should be emphasized it must be the precaution of *not exercising in cold weather while having symptoms of respiratory infections*—even for several days after the fever and fatigue has passed. For those who have EIA it is also important to practise warm-up routines at intensities that do not trigger coughing and wheezing or other symptoms ('subthreshold exercise'). These precautions must be taken seriously, even among those skiers with EIA who take pharmacological treatments. Neither regular daily medication, nor specific pre-exercise medications should be used as a substitute for careful practise of these preventive measures.

Pharmacological strategies

Asthmatic athletes may reach the top of international cross country skiing but for the athlete to achieve his or her performance potential the treatment must be individualized both with regard to asthma medication and non-pharmacological measures. The use of medications in connection with EIA should be based on pulmonary function tests (dynamic spirometry), preferably performed in connection with exercise. Because several useful pharmacological agents are in conflict with the International Olympic Committee (IOC) list of banned substances, relevant specialists in the field of respiratory medicine or sports medicine should preferably carry out the choice of medications, unless a family physician is well experienced in these issues. Even when prescribing IOC-approved asthma pharmaceuticals, it should be emphasized that the International Ski Federation (FIS) requires a statement by a respiratory medicine specialist with a confirmed diagnosis and specification of medications used by each athlete. This statement must be presented at the doping control.

The most common treatment strategy for EIA involves use of inhaled corticosteroids, either regularly or periodically, and β_2-agonists 15–30 min prior to exercise for short-acting substances, or daily (once or twice) for long-acting substances. Mast cell stabilizers, such as cromolyn sodium, may be an effective alternative to inhalation steroids in children and adolescents but are not as effective in adults. Anticholinergic agents, such as ipratropium bromide, may also be a valuable treatment alternative in some athletes, but perhaps most effective as an additional medication to β_2-agonists, if needed. Leukotriene inhibitors have recently been added to the list of treatment options and have shown promising results in connection with EIA. However, in most countries there is so far limited experience with this agent in athletic settings and, as an estimated 20% will not respond to this drug, it is not a first choice of medication in the treatment of athletes with EIA.

Regarding the IOC (and FIS) list of approved and banned pharmaceutical substances for asthma treatment, it is of paramount importance that all athletes and medical staff are continuously updated on the changes made. The latest IOC lists involve one major alteration in medications available for athletes competing on both national and international levels.
As of September 2001, the long-acting β_2-agonist formoterol (Oxis) has been approved for asthmatic athletes. At the moment of writing the following substances are allowed for use or banned in athletes with diagnosed asthma.

Approved pharmaceutical substances for asthma treatment

Short-acting inhaled β_2-agonists—salbutamol, terbutaline and albuterol
Long-acting inhaled β_2-agonists—salmeterol and eformoterol
Inhaled corticosteroids—fluticasone, budesonide, triamcinolone, beclomethasone, etc.

Leukotriene antagonists—montelukast, zafirlukast, zileuton
Theophylline—all oral agents
Inhaled ipratropium bromide
[NOTE. Please observe that FIS requires that all use of inhaled β_2-agonists and corticosteroids by competitive athletes must be verified on a signed statement by a specialist in respiratory medicine. In some cases—as in the 2002 Olympic Winter Games—athletes on β_2-agonists and glucocorticoid inhalations must provide separate respiratory tests that verifies their asthma diagnosis.]

Banned pharmaceutical substances for asthma treatment

Oral, injectable or rectal corticosteroids
Oral or injectable β_2-agonists
Adrenaline (epinephrine)
Noradrenaline (norepinephrine)
Ephedrine
Fenoterol
[NOTE. This is not a comprehensive list of all legal and banned substances for all athletes. It is only a summary of the most commonly used respiratory modulating agents at the moment of writing.]

By reading through the list of banned substances many athletes have been left with the question of what would happen if one was to become seriously ill and in the need of some of these pharmaceuticals? It should be made utterly clear that when medical conditions require the use of systemic or injectable glucocorticoids—as in strong allergic or asthmatic reactions—the athlete is entitled to this treatment as much as any other individual and this goes for any of the other banned substances as well. However, the athlete is then ‘classified’ as a patient under treatment and ‘disqualified’ as an athlete until all medications have cleared his or her system. The athlete may also be wise to carry documentation on the use of the IOC banned substances from the medical expert in charge of the treatment, when first returning to sports activities.

Main points to remember about exercise-induced asthma

- Asthma, including exercise-induced asthma (EIA), is considered a chronic inflammatory disease of the bronchial mucosa.
- EIA is characterized by episodes of wheezing, coughing or mucous hypersecretion and decreased pulmonary function in connection with physical exercise.
- Prevalences between 14 and 43% of physician-diagnosed asthma have been reported in national-level cross country skiers. The prevalence is highest in the oldest skiers.
- Factors contributing to EIA are: high intensity of exercise; exposure to cold and dry air; respiratory infections; allergens and dust; air pollution; fatigue and stress.
- Of the non-pharmacological preventive measures against EIA the most important is to avoid exercising in cold weather while having symptoms of respiratory infection.
- The use of medications in athletes with EIA must be based on pulmonary function tests (dynamic spirometry), preferably performed in connection with exercise.
- Observe that only a few asthma medications are approved for use in athletes; therefore consult the IOC list of banned substances before using pharmaceutical agents.
- Observe that FIS requires a statement by a respiratory medicine specialist with a confirmed diagnosis and specification of medications used by the athlete. This statement must be presented at the doping control.

Injuries in cross country skiing

Injury risk: is cross country skiing safe?

Traditionally, cross country skiing has been considered a relatively safe sport with few serious injuries compared to alpine skiing or other sports such as soccer. Among the cross country skiing injuries that were registered at Norwegian regional hospitals in 1997, more than 90% of the injuries were suffered during recreational skiing while only 5–6% occurred during organized ski-races. However, if we want to address the issue of injury risk in cross country skiing, it is necessary to establish an *incidence rate* of these injuries by counting the number of injuries occurring in a population for each 1000 individuals who are actively skiing for 1 day. In other words, the incidence rate is the number of injuries per thousand skiers per day. To arrive at such a figure is not easy, because it requires simultaneous registration of the number/

frequency of injuries and the number of skier days (exposure) in an identifiable group of cross country skiers (population at risk). As cross country skiing is an activity that can be performed at most times and places where snow is found and not only in organized ski-areas where number of persons and ski days may be counted, there is a considerable difficulty assessing the exposure variable (the number of skier days) when estimating injury incidence and risk.

Nevertheless, some studies have attempted to establish an incidence rate for cross country skiing and report figures from 0.4 to 5.0 injuries per 1000 skier days, with most figures in the lower end of the range. The wide range of these incidence rates indicate that several confounding variables may have influenced the accuracy of the figure, such as level of skiing skills, equipment, terrain, weather and snow conditions, etc. Moreover, being able to register all injuries—traumatic and overuse, serious and less serious injuries—in the population at risk presents an additional problem. Because there are several scientific shortcomings in the few studies that have tried to establish an injury incidence for cross country skiing, it is difficult to make a final conclusion about the safety of the sport compared to others (Fig. 4.17).

There are excellent reviews on the injuries in cross country skiing (Renstrom & Johnson 1989; Kannus *et al.* 1994; Smith *et al.* 1996). This chapter gives a brief summary of the most common injuries encountered in cross country skiing. It is hoped that the results of a recent prospective study on skiing injuries in Norway will add some updated frequency figures to the panorama of common cross country skiing injuries. It must be emphasized that the type and frequency of injuries reported from hospital and emergency wards are mostly traumatic in nature and often of a moderate to severe degree. The less severe traumatic injuries and most of the overuse injuries are treated by local physicians and often fail to be included in the database of such registrations.

The distribution and frequency of injuries may also depend upon the level of competence of the cross country skier. Elite skiers may suffer different types and degrees of injuries than recreational skiers. After a 1 year registration of all injuries in the Swedish national team during the 1983/84 season, it was reported that 75% of all injuries could be classified as overuse injuries, while 25% were of a traumatic nature. The most common overuse injuries were shin splints (medial tibial stress syndrome), low back pain and Achilles' tendon problems. Unfortunately, the injuries in this study were not registered specifically as ski- or non-ski-related injuries (running, cycling, etc.), and may therefore not give a true picture of the overuse vs. traumatic injuries in cross country skiing.

Fig. 4.17 Recreational cross country skiing is not associated with high risks of injury and should be considered a healthy and safe outdoor physical activity. However, extra precautions for cold climate activity must be taken in the way of carrying correct and sufficient clothing and survival equipment.

Non-traumatic/overuse injuries

In most cases of mild to moderate overuse injuries related to recreational cross country skiing, the injuries are not diagnosed and treated by health care professionals. Thus, reliable information about the type of injuries and their frequency is hard to find. However, elite cross country skiers frequently report their overuse injuries to sports medicine physicians and physical therapists. The list of non-traumatic injuries is therefore mostly based on clinical experience with national and international-level skiers, but may still be relevant for non-competitive skiers at all levels.

Most common overuse injuries in cross country skiing

Upper extremity

Tendonitis/tendinosis of the rotator cuff
Impingement syndrome or subacromial bursitis
Tendonitis/tendinosis to the distal triceps or proximal biceps brachii
Epicondylitis

Trunk and spine

Inflammation of muscles, tendons, ligaments or joints
Spondylolysis and spondylolisthesis
Lumbar disc degeneration, protrusion and herniation
Rotoscoliosis or Scheuermann's disease in the thoracic spine

Lower extremity

Inflammation to the hip adductors, external rotators or flexors
Minor tears or spasms in hip or leg muscles
Iliotibial band friction syndrome
Patellofemoral pain syndrome
Medial tibial stress syndrome/shin splint
Stress fractures of fibula, tibia or metatarsals
Inflammation of the tibialis anterior or Achilles' tendon
Inflammation to the plantar fascia or flexor hallucis tendon
Blisters and callosities

Several of the mechanisms behind these overuse injuries may be specifically related to cross country skiing. However, the nature of the tissue reaction and the course of repair and healing will for the most part be the same as if the injury occurred in any other sport. The initial treatment of the injuries should thus follow the 'state of the art' procedures recommended in clinical sports medicine. When managing an injured athlete—eager to get back into training—the treatment approach should be individualized and designed to optimize healing of the injured tissue. Apart from the injured structure, all other functional units of the body should be kept in regular motion and training if possible.

In all cases of overuse injuries it is important to analyse the possible mechanisms behind the injury and remove or reduce the overloading forces that contribute to the local injury. Sometimes an injury may be preceded by obvious changes in training procedures. In such cases, alteration in training modality may be the most important contribution towards effective healing of the injury. If inflammation to an Achilles' or iliotibial tendon appears during the first weeks of running in the spring, a change to biking or kayaking may be as important a part of the treatment as anti-inflammatory medications and physical therapy (Fig. 4.18). Another important 'non-medical' treatment measure in this case may be adjustment of shoes and soles or simply move from running on roads to running on a softer and more variable surface in the woods. In some situations, an injury appears without a major change in the training schedule and more obscure biomechanical factors may be involved. Nevertheless, it is necessary to identify and correct the factors contributing to the local tissue injury, even if both laboratory and field investigations of different movement patterns are required. This is particularly important when the same signs and symptoms of an overuse injury are presented several times by the same skier or appears in several of the skiers over a short period of time.

Fig. 4.18 Kayaking may be used as a supplementary training modality for cross country skiers during the summer and it may also serve as an alternative training modality to running and roller skiing when overuse injuries to the lower extremities are diagnosed.

Traumatic injuries

There are a number of ways of designating and classifying traumatic injuries. In some instances injuries are classified according to the anatomical region they affect (e.g. head injury), in others according to the type of tissue damage they cause (e.g. fracture), or a combination of the two (e.g. sprain of the knee). Based on reports from the scientific literature and clinical experience of sports medicine therapists, the most common traumatic injuries in cross country skiing are listed below.

Common traumatic injuries in cross country skiing

Head, face and eyes
Cerebral concussion
Fracture of the mandible
Cuts and skin laceration
Corneal abrasions
Ultraviolet conjunctivitis and keratitis (snowblindness)

Upper extremity
Shoulder dislocation with glenohumeral joint lesion
Rupture of the acromioclavicular ligaments with joint separation
Fracture of the clavicle
Tear of the rotator cuff
Contusion of shoulder muscles
Fracture of the humerus, distal radius or phalangies
Rupture of the collateral ligament of the thumb
Distortion of the wrist, metacarpophalangeal or proximal interphalangeal joints

Trunk
Fracture of ribs
Contusion of back muscles
Compression fracture of a vertebra body
Traumatic lumbar disc herniation
Fracture of the sacrum or pelvic bones

Lower extremity
Fracture of the femoral neck/trochanter
Contusion of hip muscles
Tear of ligament in the knee (MCL, LCL, ACL)
Dislocation of the patella
Fracture of the tibia, fibula, ankle joint
Tear of lateral ankle ligaments
Fracture of the metatarsal bones

In most instances, the traumatic injuries suffered by cross country skiers are light to moderate and successfully treated within a few weeks. However, severe injuries may happen as a result of collisions and emergency situations could arise during exhaustive ski competitions, etc. The initial treatment procedures should follow the established routines of emergency medicine and surgery, and a further elaboration on these procedures is beyond the scope of this text. The basic elements of on-site injury assessment and handling are given below.

Basic elements of on-site assessment and handling of major injuries

On-site assessment and initial handling of major injuries
Assess airways, breathing and circulation (ABC)
Stop or minimize major bleeding
Quickly assess level of consciousness (LOC)
Quickly assess possible neck injury and stabilize if necessary
Call for emergency help if ABC or LOC problems
Perform cardiopulmonary resuscitation (CPR) if necessary
Prevent or limit unnecessary damage to adjacent areas and organs

PRICE principle for initial treatment of uncomplicated musculoskeletal injuries
Protect the injured athlete from exposure to other risks of injury
Rest the limb or local area of injury in a secure and comfortable position
Ice or cool down the local area of injury unless open wounds or bleeding
Apply compression to local swelling in soft tissue
Elevate the limb or local area of injury

Regarding the handling of severely injured athletes, Inggard Lereim from the FIS Medical Commission has summarized procedures and guidelines of early diagnosis and treatment in the booklet *The Pre-Hospital Treatment of the Severely Injured Athlete*. For the

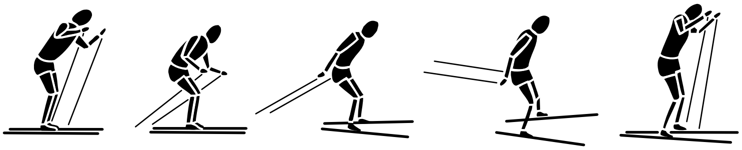

Table 4.1 Distribution of ski injuries by skiing activity and year of injury. (From Ueland & Kopjar 1998.)

	Year							
Skiing activity	1990	1991	1992	1993	1994	1995	1996	Total
Cross country skiing	201	341	383	590	510	435	493	2953
Downhill skiing	381	388	360	482	367	357	262	2597
Telemark skiing	37	39	65	60	67	73	65	406
Snowboarding	27	28	41	67	65	106	172	506
Total	646	796	849	1199	1009	971	992	6462

travelling team physician this may be useful in the evaluation of routines and procedures for emergency care—both at arenas and local hospitals in different countries. A good description of proper emergency medical equipment at sports events is also included.

The most recently published data on traumatic injuries in cross country skiing are summarized in Tables 4.1 and 4.2. The data are from a prospective study over 7 years and include all ski injuries treated at four Norwegian hospitals.

Table 4.1 shows the number of injuries in cross country skiing, downhill skiing, Telemark skiing and snowboarding, 1990–96. The difference in injury frequencies between the different ski disciplines do not represent variations in injury risk, because the number of skier days is not calculated for each sport. Rather, the difference in number of injuries between the ski disciplines may be related to the variation in the number of people participating in the individual skiing activities. One of the major findings was an increasing trend in the number of cross country injuries reported over the 7-year period. However, this may reflect better snow conditions during the last part of the study period with a larger number of people actively skiing, rather than an actual increased injury incidence.

The type and frequency of cross country ski injuries treated in these hospitals are given in Table 4.2. A total of 2933 injuries attributed to cross country skiing is registered. Sprains to the lower extremity (16.1% knee/leg and 9.1% ankle/foot) and fractures to the upper extremity (4.0% shoulder/upper arm and 8.3% lower arm/hand) are the most common injuries. Over the 7-year period the proportion of fractures compared to all other injuries increased significantly.

Another survey of ski injuries was carried out by Sherry and Asquith (1987) in Australia. Table 4.3 shows the distribution of injury location of the 88 cross country and 1538 alpine injuries registered during a winter season in a ski resort area. Similarly to the Norwegian study, injuries to the knee predominated in cross country (and alpine) skiing. Another finding was that ankle injuries were almost four times more frequent among cross country skiers compared to alpine skiers. It is likely that this is linked to the difference in support of the ankle between the cross country and alpine boots, which leads us to the issue of injury mechanisms.

Injury mechanisms

Not surprisingly, it has been determined that more than 80% of all cross country ski injuries occurred in downhill terrain. Most likely, this means that a fall to the ground or a collision with a tree, rock or another person is the preceding incident to the injury. If the skier is unable to release the poles and skies when taking a fall or hit, the ski equipment may actually cause a more severe injury than expected. An ‘entrapped’ foot in the ski-binding may cause an extreme rotation of the hip, knee or ankle when falling and thus aggravate an injury of the stabilizing structures of the joints. Additionally—particularly with the inexperienced cross country skier—the well-

Table 4.2 Distribution of type and location of cross country ski injuries in Norway, 1990–96. (From Ueland & Kopjar 1998.)

Injury	*n*	Percentage
Head/face		
Concussion	32	1.1
Laceration	55	1.9
Contusion	35	1.2
Fracture	3	0.1
Shoulder/upper arm		
Fracture	116	4.0
Contusion	84	2.9
Sprain	94	3.2
Dislocation	58	2.0
Lower arm/wrist/hand		
Fracture	242	8.3
Sprain	140	4.8
Contusion	41	1.4
Finger		
Sprain	131	4.5
Fracture	82	2.8
Contusion	21	1.4
Torso		
Fracture	174	5.9
Contusion	79	2.7
Knee/lower leg		
Sprain	471	16.1
Fracture	60	2.0
Contusion	56	1.9
Ankle/foot		
Sprain	266	9.1
Fracture	161	5.5
Multiple injuries	44	1.5
Other	288	16.6
Total	2733	100.0

Table 4.3 Distribution of location of injury in cross country and alpine skiers. (From Sherry & Asquith 1987.)

	Number of injuries (percentage in brackets)	
Location of injury	Cross country skiers (*n* = 88)	Alpine skiers (*n* = 1538)
Ankle	13 (15.0)	56 (4.0)
Knee	22 (25.0)	484 (31.0)
Leg	10 (11.0)	265 (17.0)
Thumb	7 (8.0)	101 (6.5)
Shoulder	8 (9.0)	140 (9.0)
Arm	16 (18.0)	140 (9.0)
Head/face	8 (9.0)	250 (16.0)
Trunk/spine	4 (4.5)	102 (7.0)

groomed tracks for classical skiing may represent an additional ‘harness’. The skier may not be able to adjust the direction of the skies as he or she falls to the side in downhill terrain—almost perpendicular to the direction of the tracks. A sprain or dislocation of a joint in the lower extremity is often the result. During icy conditions, these well-groomed tracks may represent a danger even for the experienced skier, when the speed picks up without the possibility of slowing down in the traditional ploughing position. This is probably the most common injury scenario for elite skiers.

The development of new ski equipment, including smaller ski-bindings, higher skating boots, lighter fibres in the skis, etc., may also have an impact on the distribution and frequency of cross country ski injuries. Such changes could either decrease or increase the risk of injury, or sometimes just move the risk of injury from one part of the body to another as illustrated by the following example. When the high skating boot was introduced, it increased stability around the ankle. Consequently, the number of injuries to the ankle may have been reduced. However, the ‘locking’ of the ankle motion by this boot translates larger forces of twisting and bending to the knee joint when the skier is subjected to rotational forces during a fall with skis and boots on. Therefore, it is important to analyse the whole chain of force reactions when evaluating the effect of changes in equipment and observe all changes in motion and technique.

Cold injuries

Local frostbite to ears, face, fingers and toes are some of the most common injuries associated with both competitive and recreational skiing. Additionally, the genital area in men and breasts in women are particularly sensitive to cooling and extra protective underwear should be used for these regions if skiing in cold and windy conditions. Initial symptoms of frostbite are discoloration of the skin, pain, numbness and, after some time, oedema and loss of sensibility may appear. Often it is the wind chill factor as much as the absolute temperature that causes these problems. When wind of 10 $m \cdot s^{-1}$ (moderate wind condition) is combined with an outside temperature of –5°C, the real effective temperature of the air blowing in the face is about –20 to –25°C. Therefore, it is imperative that all skiers are aware of the extra chilling effect of the wind and dress properly when training outdoors. Wool underwear, sweaters and pants provide both good insulation and ventilation, thus proving ideal for cross country skiing in cold weather. However, depending on the wind conditions, an extra layer of wind-protective clothing should be worn or readily available. As many recreational skiers frequently wear modern lycra suits, thin socks and gloves with a minimum of cold and wind protection, extra clothes and gloves should be carried in a backpack when out on longer ski trips.

Treatment of local frostbite depends on the severity of the tissue injury, but some general principles should be followed.

1 Superficial frostbites should be warmed up as soon as possible using steady contact with warm skin or 40°C water.

2 No external heat—directly or indirectly—should be used.

3 Avoid all rubbing or friction of the injured skin.

4 Keep the rewarming process going somewhat beyond the point where the skin becomes red, even though this may cause temporarily increased pain.

5 Keep the injured foot or hand elevated after normal temperature is reached if local swelling appears.

6 Protect the injured skin very carefully by a light bandage.

7 If lacerations of the skin occur, have a physician evaluate them for further treatment.

8 Deeper frostbites should not be rewarmed before a permanent warm condition for the injured tissue can be secured, because a refreezing will cause even larger and more severe injury.

General hypothermia may be encountered if unprepared for wind and cold temperature, especially if the skier has to stop because of bad weather conditions. Cerebral symptoms with disorientation, behavioural changes or loss of consciousness—in addition to reduced skin and core temperature—are the most common characteristics of generalized hypothermia. In severe cases, the skier must be brought inside as soon as possible and assessed for cardiopulmonary function. Resuscitation should be started instantly and emergency personnel should be called promptly if the skier has signs of cardiac arrest. If cardiopulmonary function is adequate but the skier remains semiconscious or unconscious rapid transport to hospital should be arranged.

Mild hypothermia can occur if a skier has dressed improperly during a ski trip or remains outdoors after heavy exercise without removing wet clothes and redressing sufficiently. The obvious countermeasure is to move inside if possible or increase physical activity to generate more heat before shelter can be reached. This should be done without generating too much sweat, which can cause increased cooling if having to stop skiing again. Quite frequently, cross country skiers report respiratory tract symptoms after such incidents, sometimes resulting in clinically verified infections. Good postexercise/race recovery routines, including change of wet clothes and intake of warm drinks, should prevent both athletes and recreational skiers from suffering unnecessary cold injuries and illnesses.

Back problems—an occupational risk for the elite skier?

Within the last two decades, there have been reports of increased low back pain in young cross country skiers compared to age-matched non-skiers. In one study from the USA, 58% of cross country skiers and 44% of non-skiers aged 16–21 years reported mild to moderate low back pain. A Swedish study found a prevalence of 64% of elite skiers between 16 and 25 years of age with low back pain. In a recent survey among national and international-level skiers participating in the Norwegian National Championship, 2000, 65% of all skiers ($n = 260$) reported one or more episode of low back pain within the last year. Among the skiers with low back pain, 64% were male and

36% female. Most of the skiers reported low back pain episodes in association with classical/diagonal skiing, which was similar to the findings in the Swedish study. Together, these reports suggest that competitive cross country skiing is associated with a high prevalence of back problems.

In a clinical screening of the Norwegian national team cross country skiers (*n* = 24) in 1993, Scheuermann abnormalities (increased thoracic kyphosis with a minimum of three wedge-shaped vertebra verified by X-ray) were found in 66% of skiers with no difference between males and females being observed. Reduced mobility in the affected spinal segments were also diagnosed. A characteristic among the skiers with Scheuermann's disease was that they had started systematic and specialized training for competitive cross country skiing earlier (between age 10–13 years) compared to those without this diagnosis (age 13–16 years). When examined by computed tomography scan, 31% of the athletes with Scheuermann's disease also had lumbar disc protrusion or herniation.

The recent observation of a high incidence of radiologically verified spinal injuries in world-class cross country skiers raises further concern. Among a total of 15 male national team members representing Norway in the World Championships and Olympic Games 1990–99, seven skiers (46%) have had major back injuries in the form of lumbar disc herniation and/or spondylolisthesis. Only one of these injuries was traumatic in nature. Six of these skiers have had lumbar disc surgery within the last 5 years. The mean age at surgery was 31 years and the skiers had an average of 8 years (range 6–15 years) in the national team at the time surgery was performed. Of the six surgically treated skiers, two finished their career before undertaking surgery, two skiers had to finish their international careers after surgery when rehabilitation failed to restore complete spinal functionality, while two attained their presurgery performance level. The last of the seven skiers with spinal injury did not have surgery, but finished his career partly because of major back problems. So far, only one of these skiers has won an international championship race after having completed surgery.

The fact that six of these seven skiers are several times Olympic and World Champions with a long history of enormous training loads, may indicate that certain elements of the training regimens at this level of performance are detrimental to a healthy spine. Two preliminary conclusions may be drawn from this clinical observation.

1 Spinal injuries are frequent among the very best cross country skiers of the last decade.

2 The odds of returning to international-level skiing after spinal surgery seem to be low in this group of skiers.

Consequently, two inevitable questions arise.

1 Why are such a large percentage of elite cross country skiers suffering spinal injuries?

2 What may be the reason(s) behind this unfortunate development?

As cross country skiing traditionally has been advocated as a healthy activity and actually recommended for people with back problems, this new scenario of detrimental effects of competitive cross country skiing needs to be explained. Currently, there are no scientific data available to answer these questions, but if speculation is permitted, the most obvious explanation must be the amount of training and the specificity of training that competitive skiers are subjected to. The age at which specialized training is started and perhaps the relative monotony of certain training modes may be of major importance. This could particularly apply to such training as roller skiing and double poling during the early teenage years. At this age the musculoskeletal system is not fully developed in size and strength and still retains considerable plasticity. If forced into repetitive loading patterns from the same training modality (e.g. double poling several times per week) this may result in permanent changes to anatomical structures in the spine. According to this theory, the increased kyphosis and vertebral changes observed in the skiers with Scheuermann's disease could be linked to early specialized cross country training. Whether or not this line of reasoning could apply to the cases of lumbar disc herniations in elite skiers cannot be determined at this point (Fig. 4.19).

In order to keep high speed on the tracks, the competitive cross country skier has great demand for power both in the kick and in poling. This has an impact on all loading forces in the spine. There are three basic loading patterns or direction of forces to the spinal segments:

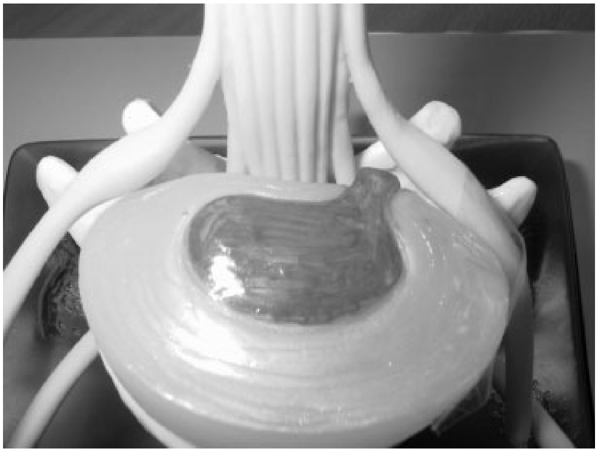

Fig. 4.19 Herniation of an intervertebral disc. Both acute and chronic overloading of the lower (lumbar) spine may cause rupture of the outer layer of the disc (annulus fibrosus). The fluid-like material will leak out into the spinal canal and down into the nearest nerve root canal. Pressure to the nerve that leaves the spinal cord at this level to innervate the lower extremity then builds up. The result is radiating pain and impaired nerve–muscle function (skin sensibility and muscular strength) in the segment of the lower extremity that this nerve is serving.

Fig. 4.20 Elite skiers seem to report more problems in connection with classical technique than skating. This indicates that the loading patterns associated with skating may be less harmful to the spinal structures than classical diagonal skiing, provided that the skating technique is performed correctly.

1 compression forces;
2 torsion/rotation forces;
3 shearing forces.

All these forces come into play when cross country skiing. Because competitive skiing has an increased demand for speed compared to recreational skiing, this will result in constantly greater force translation through the spine in elite skiers. It is therefore conceivable that even a minor overload or imbalance in the movement of spinal structures could result in microtrauma to particular tissues when repetitive loading over hundreds of training sessions is performed. Increased use of double poling in competitive skiing in the last 10–15 years has put a great demand for strength in the upper body—particularly on the ventral (front) side. It may be speculated that if strength and stability in the lower back and abdominal muscles have not been developed equally, an imbalance could lead to an incorrect loading pattern of the lower spinal segments, including the lumbar discs. Subsequently, these repetitive unaccustomed motions and forces may ultimately lead to herniation of an intervertebral disc or stress fracture of a vertebra.

Introduction of the skating technique during the 1980s with a subsequent change in both training methods and loading patterns on the spine, has also been discussed as a possible explanation for the high prevalence of back problems. However, elite skiers seem to report more problems in connection with classical than skating technique (Fig. 4.20). This indicates that the loading patterns associated with skating may be less harmful to the spinal structures than the classical diagonal skiing. When comparing the two techniques, simple biomechanical observations show that both shearing forces (bending of the spine) and torsion forces (rotation of the spine) may be greater in the classical technique. Thus, it is not surprising that more spinal overuse injuries and ailments are associated with classical skiing compared with skating.

A final but highly warranted question to be addressed is whether spinal injuries reported in connection with cross country skiing can be prevented in future generations of competitive skiers. The causal factors and mechanisms connected to back problems and spinal injuries in elite skiers can only be guessed at. Therefore it is difficult to come up with definite suggestions as to what type of training should be avoided or recommended in order to reduce the risk for spinal injuries. More laboratory studies are needed with the aim of isolating movement patterns that represent harmful loading to spinal structures. At the same time, prospective studies with the aim of improving the training strategies that produce optimal patterns of loading on the spine need to be carried out.

Main points to remember about injuries in cross country skiing

- Reliable injury incidence rates—defined as the number of injuries per thousand skiers per day—are difficult to establish for cross country skiing, but 0.4–5.0 injuries per 1000 skier days has been reported, suggesting that cross country skiing is a relatively safe sport.
- Non-traumatic/overuse injuries occur more frequently than traumatic injuries, both in recreational and competitive cross country skiers.
- The most common overuse injuries are inflammation to tendons (Achilles', iliotibialis, triceps), medial tibial stress syndrome (shin splint), lumbar disc injury and unspecific low back pain.
- The initial treatment strategy is to reduce the overloading (repetitions or force) of the injured tissue by a change to alternative training modalities and adjustment of pathological movement patterns, equipment or loading surface.
- The most common traumatic injuries are sprains to the lower extremity (16.1% knee/leg and 9.1% ankle/foot) and fractures to the upper extremity (4.0% shoulder/upper arm and 8.3% lower arm/hand).
- The initial treatment strategy for musculoskeletal injuries is protection, rest, ice, compression and elevation (PRICE), unless a serious emergency situation is evident.
- The development of new ski equipment, including smaller ski-bindings, higher skating boots, lighter skis, etc., may have an impact on the type and frequency of cross country ski injuries, both positively and negatively.
- The wind chill factor—as much as the absolute temperature— may cause cold injuries. Thus, clothes with good wind protection are vital in preventing these injuries.
- Approximately 65% of competitive skiers (age 16–35 years) in Scandinavia reports one or more episode of low back pain within the last year. The low back pain episodes are more often linked to classical diagonal cross country skiing than skating among elite skiers.
- A high incidence of spinal injuries and back problems has been observed among world-class Norwegian cross country skiers over the last 10 years. Patterns of repetitive overloading of the spine from certain training modalities may be involved in these injuries.

The team physician

A team physician may be employed by a local, regional or national ski-team. Accordingly, the extent of the physician's involvement will depend on the level of service expected from the team, the resources available for medical assistance, the number of athletes to serve and the time and interest that the team physician is willing to dedicate. Furthermore, the physician's training in a particular medical specialty and his or her area of interest in sports medicine will also have a significant impact on the approach to the job of team physician.

If working as a physician for a local ski team, medical services may be limited to office-based diagnosis and treatment of acute illnesses and injuries. Additionally, monitoring certain blood parameters, such as haemoglobin and ferritin concentrations, and a few appearances with the skiers at regional competitions may also be required. Serving as team physician for a national ski team often requires extensive involvement with both athletes and coaches, sometimes resulting in a full-time job during parts of the sports season. In this position, challenges in several non-medical tasks, such as group dynamics and team work, must be expected as much as traditional medical work in areas of sports-related illnesses and injuries: exercise physiology, nutrition, travel medicine, etc. Therefore, when involved with a national team, personal qualities may become just as important as professional qualifications for the total medical care of the athletes.

Criteria for a successful team physician

1 Personal dedication and determination
2 Good availability and accessibility
3 Well-organized work routines
4 Attitude of cooperation and a team approach
5 Broad professional qualifications
6 High ethical standards.

Qualifications

When a position as team physician is vacant, it is important that the selection process for a new candidate is fair and based on professional and personal qualifications. Selecting a physician on the basis of good qualifications rather than good ‘connections’ will ensure that future cooperation and support from other colleagues in the field of sports medicine is not jeopardized. A physician for a national team should have a combination of broad clinical experience in general medicine as well as both theoretical knowledge and practical skills in various areas of sports medicine. Even though the special skills and knowledge used as a cross country team physician may be earned through ‘field experience’ when travelling with the team, a good understanding of the many traditional clinical specialties of medicine is very important. Additionally, specific knowledge of exercise physiology, nutrition, haematology, pharmacology, doping, etc., may also be required.

It is recommended that a team physician for international-level athletes has completed basic clinical training in one of the clinical medical specialties as well as having participated in national programmes for continuing education in sports medicine. Because the team physician in most instances serves as a primary care physician for the athletes, it is not sufficient to be only up-to-date on a specific area of medicine, such as orthopaedic surgery, rehabilitation or cardiology. A team physician must be prepared to face medical challenges beyond what specialized hospital practice can give, thus a broad and solid background in general medicine is absolutely necessary.

Having advocated the need for all-round medical qualifications, it is important to emphasize a fundamental principle in medicine: *one should always recognize personal limits of medical competence and not take on medical responsibilities and tasks with insufficient experience at the risk of jeopardizing the health of an athlete*. The ability to ask for assistance, advice and a second opinion on medical issues is as important as having highly developed skills and knowledge in any field of medicine. This personal qualification is also highly valued by the athletes, because it assures them that you are always seeking the best solution to any problem that may arise. Being open to other colleagues’ evaluations of a medical problem will only improve the athletes’ confidence in you. However, with the exception of non-sport medical problems, the final decisions on the best diagnostic and therapeutic strategies must remain in the hands of the athlete and team medical staff.

Continuing education for the team physician and other medical staff is an important issue. All fields of medicine constantly face new theoretical knowledge, clinical routines and medical technology. It is impossible to stay on top of development in all areas of clinical medicine, and even in the limited field of sports medicine the drift towards subspecialization makes it hard to keep up with the latest knowledge. Nevertheless, there is an expectation from the athletes and coaches that only the best and most effective medical treatment for any ailment is acceptable for the elite athlete. Furthermore, cross country skiers are often challenging normal physiological limits in their endeavour to improve performance, thus encountering potentially negative health effects of exhaustive exercise. This makes the field of exercise physiology particularly important to a cross country team physician. The physician must also possess a basic knowledge of sports nutrition, including micronutrient supplementation, rehydration procedures and sports drinks, etc. The team physician should have a strategy on which areas of sports and general medicine to seek further proficiency in, and argue for a budget to attend relevant educational conferences. In most countries both basic and advanced courses of sports medicine are given through a continuing educational programme. International seminars with issues specifically related to endurance sports are also arranged fairly regularly and should be attended periodically.

Job contract and responsibilities

When accepting a position as team physician, a number of responsibilities and obligations are usually attached. It is recommended that this is formalized in a job contract covering the following issues.

1 The legal party (club/federation) that you are contracting with.

2 The athletes or team(s) you are responsible for.

3 Main responsibilities and tasks you are expected to cover.

4 Additional medical personnel you are in charge of.
5 Number of hours per week or days per month you are expected to be actively working.
6 Accessibility outside these hours, i.e. 'on call'.
7 What authority do you have concerning eligibility for training and competitions?
8 Who do you report to administratively?
9 What kind of budget do you have?
10 Annual compensation or wage per day/week.
11 When and how it should be paid.
12 Clothing, equipment or other goods that you are entitled to.
13 Consequence of either parties' failure in fulfilling obligations of the contract.
14 Number of months from dismissal notice to final termination of the contract.
15 Right to renewal of the contract.
16 Date for initiation and completion of the contract.
17 Signatures of both parties on two copies.

Legal issues connected to a job contract are too often overlooked or postponed in the initial phase of working with a team because medical issues are much more pressing. Then, perhaps months later, conflicts may surface—medical, administrative, economic or personal—and questions about what was said and promised at the beginning of the engagement arises. This may evolve into an unhappy situation if only minor disagreements about personal or economic compensations are at stake. However, serious conflicts may lead to a more dramatic situation where the health of an athlete could be compromised. Therefore, as in any other job agreement, a solid legal contract should be worked out and signed by the parties before starting work as team physician.

The type of responsibilities that come with a job as team physician may vary considerably according to what level of service is expected from the team, but also according to the level of involvement that the contracting physician is able and willing to provide. However, the main areas of responsibilities that are most likely to go into such a job are briefly summarized.

1 To have overall responsibility for the athletes' health in the following settings:
- while attending training at home or in organized camps; or
- while travelling and competing as a member of the contracting team.

2 To initiate any medically sound procedure that could prevent or reduce the risk of sports-related illness or injury.
3 To provide swift and correct diagnostic routines and medical treatment for any acute illness or injury among the athletes.
4 To monitor the athletes' health and risk of illness or injury along with their training load and total life stress and take preventive action if signs of deteriorating health and performance occurs.
5 To initiate necessary treatment for acute illnesses and injuries that occur among the non-athletic members of the team while on tour.

These and perhaps other areas of responsibilities should be discussed with the team manager and the appropriate statements brought into the contract accordingly. This will make the team physician's work more predictable and all parties will thus have the same understanding of which duties and authorities are part of the job.

Management and organization

As indicated in the professional title, the team physician is part of a *team*, consisting of athletes, coaches, managers, technical assistants, waxers, etc. (Fig. 4.21). The internal organization of a national cross country ski team may differ somewhat from one country to another, but normally the physician is administratively subordinate to a non-medical team manager. At the same time, the team physician may be in a position of leadership of a medical staff consisting of assistant doctors, physiologists, physical therapists, nutritionists, massage specialists, etc. In such a position it is necessary to follow the 'line of duty' concerning both medical and non-medical issues. Furthermore, regardless of differences in team organization, it is imperative that all members of the team are clear on the areas of responsibility and authority and who reports to whom. This requires effective lines of communication between all team members, including the athletes (see Chapter 7, section on Group dynamics).

A typical national team in cross country skiing may consist of 8–10 skiers, 3–4 coaches, 5–6 waxers, 1–3 team physicians and 3–4 physiotherapists, a physiologist, and a team manager. The team physician may also serve additional teams of skiers and their

Fig. 4.21 A national cross country team consists of people with a variety of skills and duties including athletes, coaches, managers, waxers, technical and medical staff. A teamwork approach to most tasks from all professions involved is needed to provide the best opportunities for athletic success.

coaching staff. Therefore, awareness of team dynamics and communicational skills is needed both among the medical staff and in the sports team as a whole. Many teams have realized that close cooperation between the medical and coaching staff is of vital importance for the success of the individual athletes. Similarly, a team approach among the members of the medical staff to the athletes' health problems is just as important in order to optimize treatment and rehabilitation. Regular medical staff meetings and briefings are recommended both at 'home base' and on race tours. This will secure a proper flow of information on the health status of each athlete and good coordination of the selected treatment strategies.

In today's society, with an array of medical and paramedical services being offered to the public, it is necessary to have a policy on how the athletes should interact with this multitude of health businesses. The high-profile athlete is particularly attractive for the promotion of specific health services, methods of treatment or health products. Furthermore, in most countries each person has the right to choose his or her own therapist to deliver a specific treatment or health service. However, in this free market of medical services it is important to be aware of the negative aspects and pitfalls of free enterprise, both for the athletes and the medical support team. *Thus, it is recommended to have a policy of allowing the athletes free access to all health care services outside the medical support team but, at the same time, insisting on being continuously informed about all new health problems and who is responsible for the diagnostic and treatment process*. In other words, as the team physician you have the right to know but not to determine what medical services the athletes are choosing. If the team physician should disapprove of the athlete's choice of medical services, the parties involved must quickly resolve this problem and reach a mutual agreement. In order to have a well-functioning medical team both at home base and during travelling, it is important that the team physician is continually updated on each athlete's health situation. This 'freedom with responsibility' policy should be an acceptable—middle of the road—solution between restricting the athletes to use only the medical support team and allowing a liberal 'supermarket shopping' of medical services without quality control.

Handling a variety of health problems within a sports team requires an extensive network of quality medical services. The team physician needs good access to common diagnostic and treatment facilities and preferably a personal relationship with colleagues in various fields of medicine. This is not a strategy for acquiring a superior health care system for athletes compared to the general public. In many instances a short conversation and piece of advice from a medical specialist is the only service needed. However, for elite athletes it is of paramount importance that a minimum of time is spent out of training.

It is a common experience for team physicians that the traditional health care system has a general lack of knowledge on sport medicine and athletic care. Therefore, the network of medical services outside the sports team must be carefully chosen among those health professionals that at least have a minimum of insight and interest in sports and athletic performance. Unfortunately, a 'mirror image' of ignorance and lack of insight may turn up on the athletes' side as well. In some situations athletes do not show the proper respect for good medical evaluation and ignore expert advice just because it is given by medical expertise without a background in sports medicine. As a result, the athletes may end up with undesirable and possibly dangerous outcomes of their illness or injury. Therefore, one of the most important tasks for the team physician is to bridge the gap between the medical and athletic expertise, both inside and outside the sports team.

Practical preparations

When starting as a new team physician, it is important to gather as much medical information about the athletes as possible from the previous physician and the other medical staff. Each athlete's health condition should be evaluated at the beginning of the training season and, based on the outcome of this evaluation, the team physician should initiate necessary measures to reduce or eliminate each individual's health problems (Fig. 4.22). Keep an updated medical file/log on each athlete, but adequately stored as confidential information. Furthermore, remember to bring in the necessary specialist statements if an athlete is on medication with restricted use during sports activities. The task of educating the athletes and establishing optimal routines in the following areas may be one of the most important jobs for the team physician.

Fig. 4.22 Training preparations for the athletes start early in the summer, often including altitude camps. A well-organized plan for proper medical support should follow these early preparations.

Teach the athletes about the following

- Risk factors for common injuries and illnesses related to cross country skiing.
- Important preventive measures towards these illnesses and injuries.
- How to cope with initial signs and symptoms of illness and injury.
- How to adjust their training while injured or sick.
- How to practise optimal recovery regimes between their training sessions.
- Banned substances and methods in conflict with present doping rules.
- How to check medications, nutritional supplements and other substances.
- How to deal with adjustment of time when travelling long distances east or west.
- How to deal with adjustment to hypoxia when training above 1500 m altitude.

Make arrangements with the head coach or sports manager in sufficient time before the season to evaluate and discuss each year's season plan for training, travelling and competitions with regard to all health matters, then organize sufficient coverage of various health personnel for the scheduled events. Adequate medical equipment, including necessary medications, should be prepared in time before travelling with the team. Moreover, proper routines for monitoring the athlete's training state and life stress, including relevant blood tests, should be discussed with both athletes and coaching staff. Preventing overtraining syndromes with potential harmful health effects is a mutual responsibility of the coaching and medical staff.

While travelling, try to organize the change in locations with a minimum of risks for infectious gastrointestinal and respiratory illnesses. Check hotel rooms and eliminate factors that might aggravate an allergic condition for an athlete and check the sanitary conditions in hotels and restaurants where the team is eating. Remind the athletes to avoid close contact with people carrying contagious diseases. If contagious diseases should appear, quickly isolate the sick person and, if possible, his or her room-mate. Restrict training and competition for 1–2 days after the disappearance of fever and malaise in cases of infectious diseases (for more detailed practical guidelines concerning how to minimize risk of illness and how to deal with infectious diseases, see sections on Immune system, and Prevention of infections).

Psychosocial responsibilities

The team physician has an obligation to be concerned with the athletes' mental and social well-being as well as their physical health. With respect to both general health and athletic performance, it is important for the athlete to be in a state of good psychological balance and to thrive in the social life of the team. Therefore, all members of the medical support team have a major responsibility in optimizing life quality in the athlete's home setting as well as in the team. As most members of national teams often spend more than 6 months of the year together, the personal input on the 'psychosocial arena' from each member of the coaching and medical staff becomes vital for the team spirit. Therefore, it is important that the medical staff promote various social activities such as playing musical instruments, cards, pool, trivia; attending concerts, shows and exhibitions; as well as visiting museums, galleries and restaurants. A shopping tour or simply an evening 'walk and talk' with a team member who might need a little extra attention and support may be as important as prescribing the correct medication for an illness. All team members are bound to have their 'ups and downs' during a long season, and it is imperative that the medical staff register these fluctuations and do everything they can to counteract both individual and collective negative mood swings.

In endurance sports such as cross country skiing there is an increasing number of athletes who continue their careers beyond the age of 30. Skiing is then often combined with family life and the athlete has more obligations at home compared to team members who are single. This change in life situation is important to recognize both for the athlete, the coaches and the medical staff. It may lead to more stress and less opportunities for optimal recovery after training sessions. Furthermore, having athletes with spouses and children will lead to situations where the team physician has to attend to various medical and/or psychosocial problems in the athlete's family. The team physician should be prepared to deal with family medicine issues when asked to do so by the athlete and family. However, if not comfortable with this role, the team physician should refer to a local physician for closer evaluation and follow-up.

Handling medical information

The team physician and others members of the medical support team must always be aware that they are handling privileged information when an athlete's health problem is discussed. Although the medical staff also has a need for—and right to—appear as a private person in some situations, *it is wise to use the general principle that all information about health and personal matters from any member of the team should be considered privileged and confidential*. It is important to stress the point that not only information directly connected to illness and injury, but also information on personal, family and social matters is privileged material—unless specifically stated otherwise. Despite the fact that all medical personal have made a pledge to confidentiality of medical information, it does not mean that such information should be passed freely among the medical staff of a team. Only information relevant to the treatment of a specific medical condition in an athlete should be shared among the medical staff. Confidential information on other health and personal issues should not be shared with other medical staff members. However, what information may be considered relevant to the medical care of an athlete has to be evaluated from case to case.

Does this mean that medical information cannot be discussed with non-medical personnel in the team? The answer is definitely yes, unless the athlete him or herself releases the medical information to someone in the coaching staff or other non-medical members of the team. In order to make a sports team work smoothly and effectively, each athlete should make a general agreement with the team physician—orally or in writing—on what kind of medical information can be discussed with whom. This has to be accompanied by individual evaluations from case to case, where the physician asks the athlete specifically what information should or should not be discussed with non-medical persons. These routines should always be followed very carefully. Even though the athletes in many instances do not mind the sharing of 'unharmful' medical information, only one case of carelessness in these matters is sufficient to destroy the trust that a good doctor–patient relationship is based upon.

Fig. 4.23 When the media wants information on medical issues regarding an athlete, the best solution is to have the athletes themselves make the comments they feel are correct. Thereby, the team physician may avoid disclosing confidential information without the athletes' consent.

Media contact

Special warnings regarding the flow of medical information has to be emphasized with today's intense media focus on sports. This applies not only to national and international level athletes, but also to the 'local heroes' covered by media in the region where the athlete lives. Again the basic rule is that only the athletes themselves can give medical information to the media (Fig. 4.23), unless having agreed to release certain information to the media through the team physician. Within a team there are individual differences in how much medical information each athlete would like to share with the media. Thus, it is imperative for the team physician to establish proper limits for such information with each athlete and respect the individual needs for confidentiality.

However, in reality it is impossible to always have a clear agreement with every athlete—in each case of illness and injury—about how much medical information may be shared with the media. Therefore, if uncertain about medical comments to the media, make the reporters themselves ask the athletes, and thus avoid violating the rule of privileged medical information. Another strategy when approached by the media is to ask for the necessary time to discuss the issue with the athlete before making a statement. In any interaction with the media it is advisable to either say nothing or tell the truth. You may not need to tell the complete story, but never lie!

If medical problems arise among some of the most focused and at times 'haunted' athletes on the team, it may be a good strategy to have the team physician face the media in order to 'divert pressure' and protect the athlete from excessive stress. This situation might arise just before or during major championships. Handling this job correctly may be very important for the well-being of both the athlete in focus and the team as a whole. Needless to say, frequent interaction with the media can be stressful to a physician not used to this type of international media focus. Therefore, it is well worth having planned for such scenarios ahead of time. Both the medical support team as well as the whole sports team should agree upon some basic media strategy and preferably practise some routines ahead of major sports events.

Ethical dilemmas

Whether practising as a team physician locally, nationally or internationally, ethical challenges will appear and must be dealt with. In its most simple form, it may be a question of whether a skier should enter a race without having completely recovered from an injury or illness. At the other end of the scale, it may be about using questionable or downright illegal methods or medications to improve the performance of an elite skier. No physician is totally immune to the influence of 'outside' pressures that challenge his or her fundamental ethical standards, nor to 'inside' suggestions from athletes, coaches or managers to move across ethically sound lines in the treatment or preparation of athletes. For a team physician it has to do with both medical and personal ethical standards when difficult issues are raised, and these standards may be different from one physician to another without one set of ethics being objectively right or wrong.

In the case of starting or holding back an athlete who feels fit, but still running an increased risk of suffering a relapse of a not fully recovered illness or injury, the decision is not always clear-cut. The probability of suffering new problems, the severity of possible injury or illness relapse, the length of recovery time, the importance of this competition compared to others later in the season and several other considerations will affect the decision. The most important thing is to discuss these issues with the skier and simply ask his or her opinion. Ideally, athlete and physician will be in agreement, but if the athlete wants to leave it up to the physician, the doubt should always count in favour of health and recovery rather than a questionable start. If the skier is of the opinion that starting a race is not favourable to his or her health, the physician should always see to it that no pressure from coaches or managers will influence the decision as long as it is medically sound.

As much as the decision regarding a skier's possible entry in a competition is difficult—and has to be made without specific rules and guidelines—the decision not to get involved in doping-related activities should be easy for a team physician. Nevertheless, the involvement of one or more physicians in a recent episode of systematic doping of cross country skiers has shown that it is not so easy and straightforward in practice. Unfortunately, there are strong indications that during previous years several other physicians and medical staff linked to cross country teams from different countries have been using illegal methods and medications to enhance the performance of their skiers. Motives may range from unrealistic personal ambitions and an 'eager to please' attitude to national glory and fame, perhaps mixed in with a little money and power for some physicians. Circumstances may be a coach- or athlete-induced 'pressured' manoeuvre for improved recovery (such as an injection of anabolic steroids), or a team decision for full-scale systematic doping of several skiers.

No matter what the motives or circumstances behind doping may be, when practising as a team physician there are certain absolute rules and regulations laid down by the FIS and IOC that must be followed. It is imperative that the team physician is familiar with these rules and regulations but, more importantly, that no person or circumstance may lead the physician to break these rules. *The personal ethical standard of the team physician can be the most important preventive measure against doping in a sports team*.

In some instances, illegal medical practice and straightforward doping may be initiated by the physician him or herself. This is absolutely unethical and a criminal offence both in the medical field and within the sports community. However, in other instances a team physician may be 'involuntarily' involved in illegal medical manoeuvres and doping because of questionable or poor judgements in other parts of medical practice or life in general. The mechanics of the 'partners in crime' strategy probably works as well within a sports team as it does in other social settings. Therefore, any team physician should avoid getting into a compromising situation rendering him or herself more vulnerable to the development of unethical and illegal activities in the team. If put 'under pressure', it is important to report this to a proper authority immediately, even though this may seem difficult at the time.

On the supposition that the team physician is not involved in doping activity, how should he or she react to a positive drug test on one of the skiers in the team? Such cases are very delicate and difficult to handle—including huge media coverage if it should involve a well-known athlete. Even if much of the team physician's effort is focused on how to avoid such an incident, it is best to have thought through a 'worst case scenario' and have a strategy on how to deal with this. It is important to have discussed it with the rest of the medical team as well as the manager and coaches. Athlete confidentiality and limitation of information before both the A and B sample is analysed are key issues if such a situation should occur. Furthermore, it is important to respect the test results and accept the findings, without arguing that there must be something wrong with the testing or that this could not happen to one of your athletes. This attitude and initial position is not in conflict with the other important obligation of caring for the athlete as his or her personal doctor and friend. No matter if the positive drug test is a result of deliberate or accidental intake of banned substances, it creates a personal crisis where human support is vitally important. However, it is crucial that the team physician is able to separate these two parts of the job and act professionally.

The physician may get involved in activities or methods of improving athletes' performance that are not illegal—neither medically nor according to the FIS/IOC rules—but still debatable as to the ethics of such practice. Administration of intravenous liquids and nutritional solutions to an athlete for the purpose of speeding up recovery between two competitions is an example of sports medicine practice that can be controversial. Injection of local anaesthetics before a competition to remove pain from an injury is now restricted within the last 24 h according to FIS doping rules, but nevertheless not always practised by all team physicians. Even within the legal time frame, this practice may sometimes be considered questionable both medically and ethically. Use of altitude simulating facilities—including tents, single rooms or entire houses has been increasing in skiers from different countries, and several champions in the last world championship and Olympic games had used that approach. So far there is no restriction on the use of such facilities, and under proper medical supervision there is no known health risk linked to living at moderate altitudes (below approximately 3000 m) under these conditions for a limited period. However, the use of such facilities, whether one considers altitude simulation a necessary and convenient step in the acclimatization process for altitude competitions or a threat to a healthy and socially acceptable development of sports, should be discussed. IOC, FIS and World Anti-Doping Agency (WADA) should also make a clear ruling on whether they are legal or not.

Several other 'not illegal' means and methods for improving acclimatization (to heat, cold, altitude, etc.), training effects, regeneration, recovery and performance do exist, and certainly more will come in the future. *It is the physician's duty to avoid the use of any medical treatment or physiological manipulation that comes into conflict with the rules and regulations of the sport, even though the means, methods or medications used are not yet classified as doping.* Furthermore, it is imperative to emphasize that the use of any banned medical treatment or physiological manipulation must be avoided, *regardless of whether or not it may be disclosed in a doping control.* Having been in the international cross country field for several years and observed the increasing 'medicalization' of this sport, it is my sincere opinion that the future of cross country skiing is to a large extent linked to the ethical standard of the team physician. This is a formidable challenge; thus an open discussion on all ethical aspects of the sport is more than welcomed.

Main points to remember about the team physician

- Personal qualities may be just as important as professional qualifications when working as a team physician.
- It is recommended to formalize the work with an athletic team in a written contract covering the main responsibilities, obligations and rights of the job.
- Basic knowledge on exercise physiology, sports nutrition, fluid replacement, recovery measures and doping-related issues must be acquired in addition to more detailed knowledge on common injuries and illnesses.
- Continuing education and updates on sports medicine issues should be pursued systematically.
- The ability to ask for a second opinion and to take advice from a colleague on difficult medical issues is important.
- Teach the athletes proper procedures for doping controls, optimal routines on recovery, prevention of infections and other medical issues (see text boxes).
- Medical equipment and supply of medications should be prepared in adequate time before travelling with the team.
- Medical staff members have a responsibility to deal with the psychosocial issues in the team and optimize life quality in the athlete's home setting as well as while travelling.
- All information regarding health and personal issues from any member of the team should be considered privileged and confidential.
- Each athlete has to agree on what kind of medical information can be released and discussed with whom, including the media.
- If permitted to share medical information with the media, never lie; tell the truth, but not necessary the whole truth.
- The team physician must be prepared to handle pressure both from outside and inside a sports team on issues that challenge his or her fundamental ethical standards, both personally and professionally.
- It is the physician's duty to avoid the use of any medical treatment or physiological manipulation that comes into conflict with the rules and regulations of the sport, even though the means, methods or medications used are not yet classified as doping.
- A 'worst case' scenario on how to handle a case of positive drug testing must be prepared by the team physician, managers and coaches.

- The ethical standard of the team physician may be the most important preventive measure against doping in any athletic team.

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Chapter 5

Special and practical issues in cross country skiing

Overreaching and recovery from training

Overreaching and overtraining syndrome

Overtraining process

In any training process with the purpose of improving performance, the challenge is to balance total training load with adequate recovery measures that over time will lead to adaptation, regeneration and, ultimately, performance enhancement. During normal overload training the performance capacity improves after recovery for 1 day (see Fig. 5.1 and Chapter 3, Training). During periods of intentional prolonged overload training (during overreaching) the performance capacity of the athlete decreases. However, after a few days of enhanced recovery a super-compensation effect may be attained (Fig. 5.1). Athletes have to try to find the highest possible total training load their body can cope with and to increase that training load gradually. If an individual's upper limit of stress tolerance is passed because of excessive overreaching, insufficient recovery and/or the existence of some additional stressors, the athlete may enter a process of overtraining: persistent fatigue, loss of appetite, menstrual dysfunction, performance decrease, neuroendocrine and immunological changes, alterations in mood states, etc (Table 5.1).

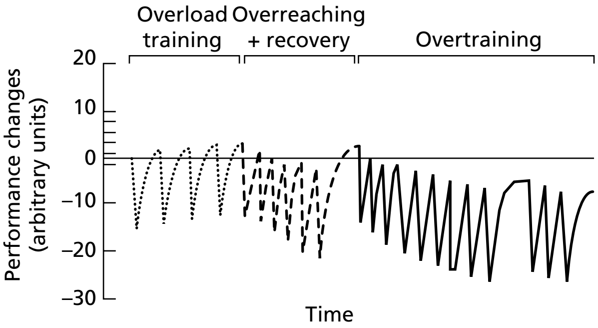

Fig. 5.1 Schematic description of performance changes during overreaching–overtraining process. After overreaching and consequent recovery, performance capacity is improved. Excessive overreaching and insufficient recovery may lead to decreased performance and overtraining syndrome.

Overreaching has been defined as an accumulation of training and non-training stress resulting in short-term decrement in performance capacity with or without related physiological or psychological signs and symptoms of overtraining in which restoration of performance capacity may take from several days to weeks. Overtraining has been defined as an accumulation of training and non-training stress resulting in long-term decrement in performance capacity with or without related physiological or psychological signs and symptoms of overtraining in which restoration of performance capacity may take several weeks or months.

The mechanisms underlying overreaching and overtraining seem to be related to the function of the autonomic nervous system. Both stress of training and non-training stress increase the activation of the sympathetic nervous system (SNS) so measurement of SNS activation can be used to evaluate the amount of total stress of the body. Similarly, good recovery is related to high activation of the parasympathetic nervous system (PNS). Indeed, two types of overtraining syndrome have been described in the literature: sympathetic and parasympathetic (Table 5.1), which seem to represent different stages of the overtraining process. During the initial stages of the overreaching–overtraining process, signs and symptoms of sympathetic activation are dominant. If overtraining continues, indications of both sympathetic and parasympathetic activation can be observed. If the overtraining process continues further, all the functional reserves of the body may be exhausted and the athlete may enter a stage where the parasympathetic signs and symptoms start to dominate and the restoration of performance capacity may take several weeks or even several months. During low-intensity distance training the overtraining process does not include the sympathetic stages and the skier may have difficulty in recognizing the difference between positive

Table 5.1 Typical signs and symptoms of sympathetic and parasympathetic types of overtraining syndrome.

Sympathetic	Parasympathetic
Impaired performance	Impaired performance
Restlessness, irritability	Fatigue, depression
Disturbed sleep	Sleep not disturbed
Increased resting HR	Low resting HR
Increased resting BP	Low resting BP
Retarded recovery	Fast recovery of HR
Postural hypotension	Decreased exercise HR
Decreased Bla_{max}	Decreased exercise $\text{Bla}_{\text{submax}}$
Decreased appetite	Hypoglycaemia during exercise
Weight loss	Phlegmatic behaviour
Increased incidence of injuries and infections	
Loss of training desire	

Bla, blood lactate concentration; BP, blood pressure; HR, heart rate.

training effect and parasympathetic type of overtraining symptoms because they can be quite similar. However, some changes in resting and standing heart rate responses may be used.

Control of training state, recovery and overtraining in field conditions

At the beginning of the training career of a young skier the coach should start to teach the skier to recognize his or her training state: does the skier recognize the typical signs and symptoms related to overreaching and overtraining process; is he or she coping well with the stress of training and responding positively to training; and is he or she understanding the necessity of improved recovery after demonstrating the signs and symptoms of overtraining syndrome? This learning process should include subjective self-evaluations in the training log, questions and answers related to the typical signs and symptoms of overreaching and overtraining process, questions on the quality of training and recovery, and measurements of different physiological functions known to be related to the overtraining process.

Table 5.2 Autonomic nervous system influences heart rate (HR) and heart rate variability (HRV) variables in the orthostatic test. (From Uusitalo 1998; Uusitalo *et al.* 1996, 2000.)

Parasympathetic activation	Sympathetic activation
Decreases HR_{sup} and HR_{stand}	Increases HR_{sup} and HR_{stand} >1 min after standing up
Decreases HR_{peak} and HR_{min} (biphasic HR response) after standing up	Increases slightly HR_{peak} during first 30 s after standing up
Increases supine and standing HRV-variables	

The following measurements can be used to evaluate the training state.

1 Measurement of the stress response at rest and during exercise, e.g. adrenalin, noradrenalin, adrenocorticotropic hormone (ACTH), cortisol, cardiovascular autonomic function tests.
2 Measurement of anabolic and catabolic reactions, e.g. testosterone, cortisol, end-products of protein metabolism such as urea.
3 Muscle overload measurements, e.g. lactic dehydrogenase (LDH), creatine phosphokinase (CPK) and myoglobin concentrations in blood.
4 Measurement of immune functions.
5 Performance measurements, e.g. heart rate and blood lactate vs. velocity.
6 Questionnaires, e.g. mood states, emotions, training load vs. recovery (see Chapter 6, Psychology).

Many of those possibilities require laboratory analysis of blood samples and the feedback may take days or weeks.

Orthostatic heart rate test

Athletes need an immediate feedback system that they can use themselves in field conditions. Cardiovascular autonomic function tests based on heart rate (HR) and heart rate variability (HRV) measurements have been developed to evaluate the function of the sympathetic and parasympathetic components of the autonomic nervous system (Table 5.2). The simplest cardiac autonomic function test that can be used in field conditions is the orthostatic heart rate test. The simplified

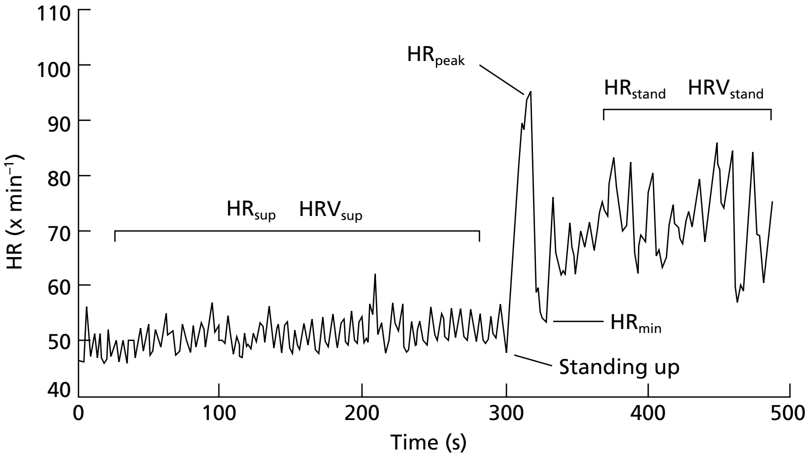

Fig. 5.2 Typical beat-by-beat heart rate curve in the orthostatic heart rate test. Heart rate (HR) calculated from every beat-to-beat R-R interval fluctuates according to breathing frequency. Heart rate variability (HRV) is calculated from both supine and standing period. Typical HR and HRV variables as well as their interpretation are presented in Table 5.2.

modification of the test consists of a 5–10 min supine resting period after which the athlete stands up and stays in a standing position without moving for 3 min. During the 5-min period before standing up and during the 3-min standing period, heart rate is recorded using a polar heart rate monitor (beat-by-beat recording). The typical heart rate curve is seen in Fig. 5.2.

Sympathetic activation (stress) increases supine (HR_{sup}) and standing (HR_{stand}) heart rate while parasympathetic activation decreases both supine and standing HR. When standing up the acute increase in HR (HR_{peak}) is mainly parasympathetically controlled. In addition, parasympathetic activation increases HRV. If the ability to recover is good, HR_{sup} is low, HR_{peak} does not increase very much after standing up, and HRV during both supine lying and standing is high. Several studies have shown that experimental overreaching and overtraining lead to increased HR_{sup} and HR_{stand} and decreased HRV, while increased variability is observed when performance is improved (Figs 5.3 and 5.4).

In an experimental training study on young cross country skiers, the changes in HR variables were related to the changes in performance of young cross country skiers (Fig. 5.3). In that study most 15–17-year-old skiers replied to a questionnaire—comprising about 80 questions—that they did not have enhanced stress, were not fatigued, did not experience any psychological or physiological signs related to the overtraining process and that they were well recovered. However, at the same time, their performance in the laboratory tests had decreased significantly and they had many physiological signs indicating overtraining, e.g. increased resting heart rate and raised blood pressure (Fig. 5.3).

Altitude training studies also indicate that HR_{sup} and HR_{stand} reflect the stress caused by hypoxia and acclimatization to hypoxia and that HR values are related to the changes in performance during the altitude training camp (see section on Altitude training).

For a rough estimation of SNS and PNS function, the mean HR during the 8-min recording period can be used. The higher the mean HR the greater the sympathetic activation and the lower the parasympathetic activation. However, much more information can be attained by detailed calculation of HR and HRV parameters. This requires beat-by-beat R-R interval (RRI) recording and the use of time and frequency domain analysis of HRV. Total and high-frequency power of HRV have reflected the changes in $\dot{V}O_{2max}$ during experimental overreaching–overtraining periods and during demanding training camps (Fig. 5.4).

Because any single HR or HRV variable cannot alone unambiguously indicate changes in SNS or PNS function (in the training state of an athlete), an overtraining test program (Polar Electro 2001) has been developed to calculate 'overtraining index' from several supine and standing HR and HRV variables (Fig. 5.5). The program also calculates individual reference values for each athlete and compares his or her overtraining index to the athlete's own reference value. Based on the index and the changes in HR and HRV variables, the program evaluates the training state of the skier using the following statements.

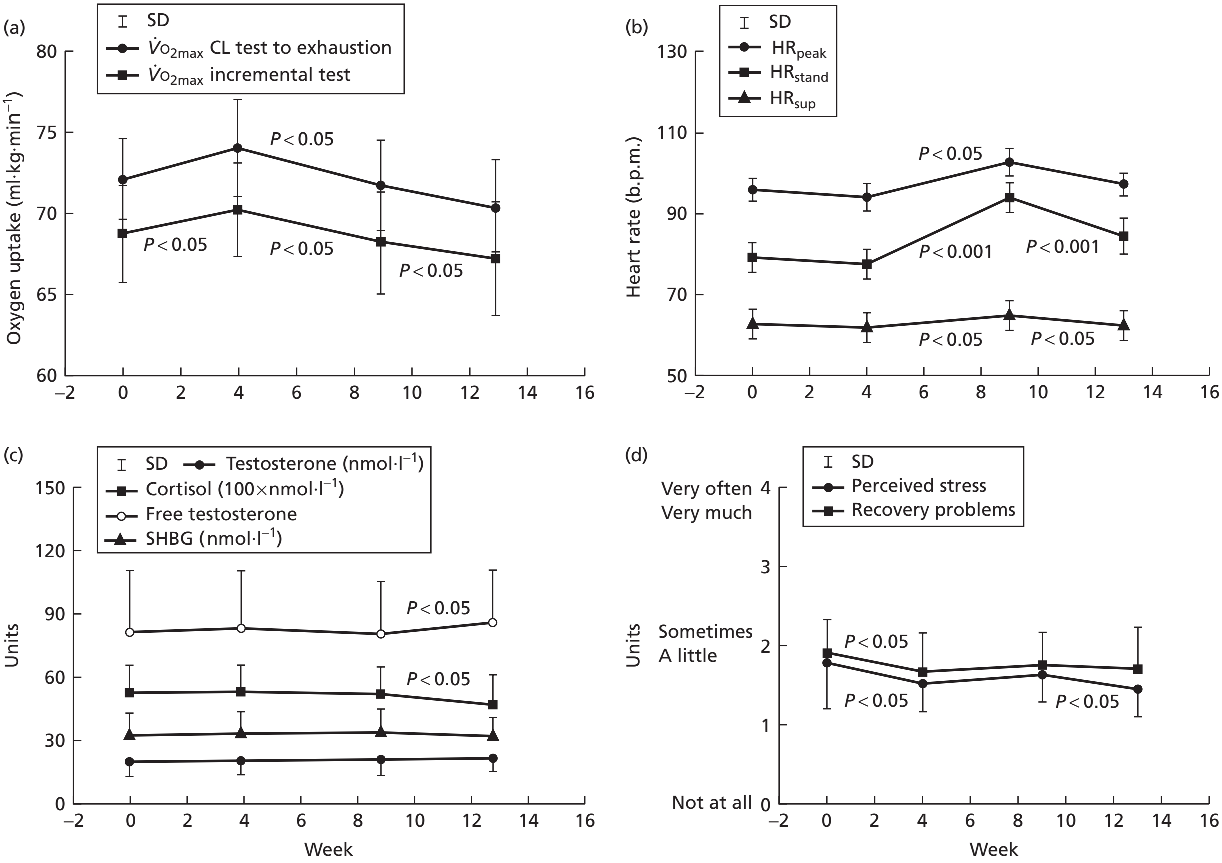

Fig. 5.3 Overreaching and overtraining of young cross country skiers ($n = 39$). A demanding summer training period induced a performance decrease in young cross country skiers but subjective feelings did not reveal that performance capacity had decreased. Resting and standing heart rates were increased at the same time as performance on the treadmill had decreased. No significant changes were seen in testosterone and cortisol concentrations. Increase in HR_{peak} suggests parasympathetic withdrawal and increase in HR_{stand} sympathetic activation. Skiers whose HR_{peak} increased from week 4 to week 9 demonstrated decreases in $\dot{V}O_{2max}$, while skiers with decreased HR_{peak} could improve their $\dot{V}O_{2max}$. Significance of changes has been given.

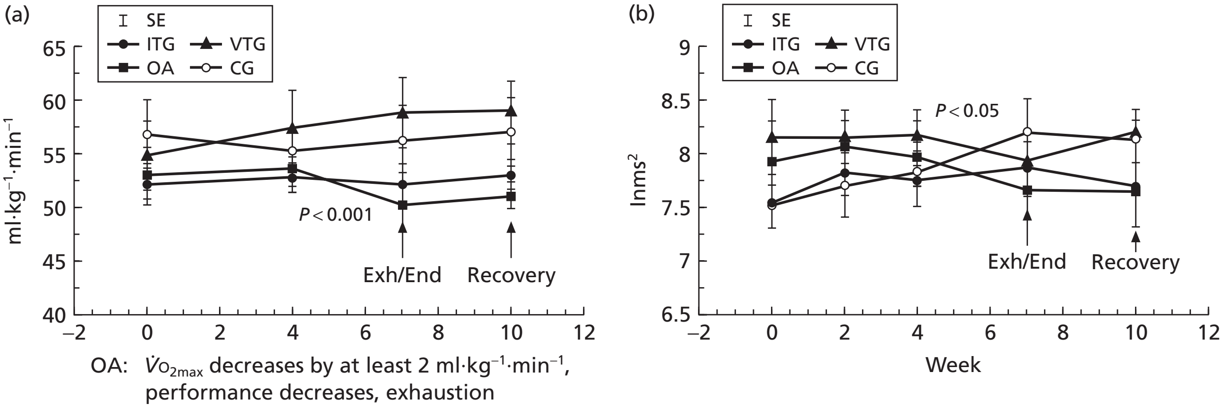

Fig. 5.4 (a) During experimental overreaching in female endurance athletes $\dot{V}O_{2max}$ improved in the group that increased training volume (VTG) ($n = 6$). Some of the athletes who increased their intensive training (ITG) ($n = 12$) demonstrated a decrease in $\dot{V}O_{2max}$ (OA) ($n = 5$). (b) As an example of the HRV changes, the total power of standing heart rate variability changed similarly to $\dot{V}O_{2max}$, indicating that HRV variables reflect the changes in performance (and training state). No changes were seen in the control group (CG, $n = 5$).

- Good recovery, positive training effect.
- Maintaining training effect.
- Still maintaining training effect—should you check your training programme?
- Acute training response, or some other stress factor such as getting sick—do next test after an easy training day.
- Overreaching, or some other stress—should you have a few days' easy training?
- Signs and symptoms of sympathetic or mixed overtraining syndrome—do next test and check training state after a few days' easy training.
- Danger of exhaustion—signs and symptoms related to parasympathetic overtraining syndrome.

The statements have to be compared with the subjective feelings and evaluations of the skier and his or her coach and with the objective data from training and performance. In Chapter 6 (section on Psychology) a questionnaire is presented which allows calculating a balance between training stress and recovery (Table 6.2). The following section gives practical advice on how to optimize recovery and minimize non-training stress factors.

Optimizing recovery from training

Recovery in sports may be defined as the restoration of physiological and mental disturbances caused by a combination of training and non-training stressors. Athletes and coaches plan their training programmes and many skiers do their training exercises exactly as planned. Too seldom skiers and coaches remember that improvement of the different determinants of performance occurs during recovery (see Chapter 3, section on Principles of training). Therefore, if the total training load and strain of athletes is increased the recovery measures also have to be improved. This means that, in addition to planning training schedules, recovery activities before, during and after training have to be planned as well. Implementing improved measures of recovery from training stress may be an effective way of improving adaptation to and tolerance for the total training load. In other words, in certain periods when training stress is significantly high, optimal recovery regimes may be as important as the training itself for performance improvement. To balance out the many

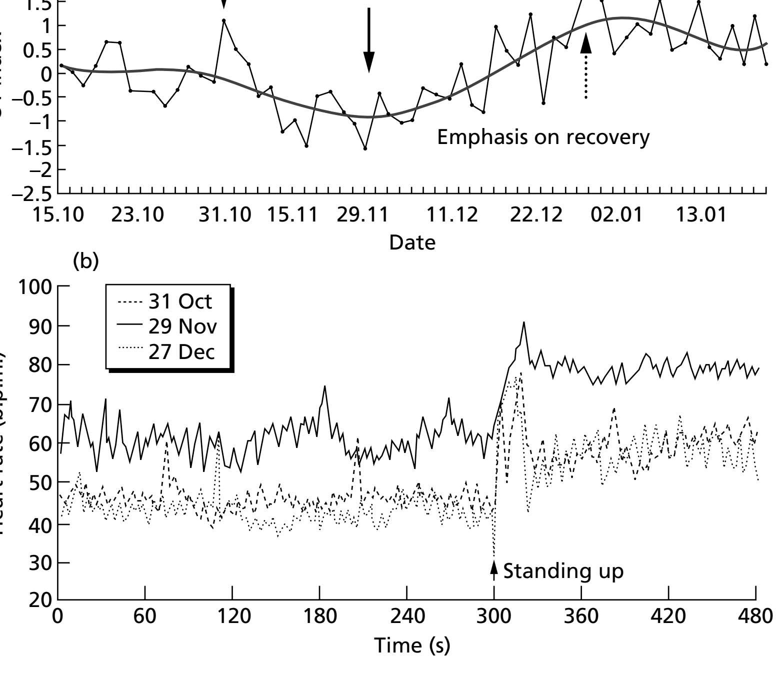

Fig. 5.5 (a) Changes in training state based on the orthostatic heart rate responses using overtraining (OT) index during demanding November training and lighter training thereafter. Individual reference value is calculated and is shown as the zero line. Values in the *y*-axis denote individual standard deviations from the reference mean. (b) During overreaching–overtraining heart rate in supine and standing position is increased and variability, especially during standing, is changed. During enhanced recovery and tapering, heart rate decreases, heart rate variability increases and overtraining index indicates positive training state. The arrows indicate the time points of the corresponding orthostatic heart rate curves. (Rusko, unpublished data.)

adverse disturbances of training stress with positive measures of recovery will subsequently put the body in a position where even more physical and mental stress can be tolerated at an improved performance level. Also, decreasing non-training life stress will further improve the outcome of training.

To guarantee sufficient recovery during and after periods of demanding training, the following guidelines based on experience in working with national ski teams and on some scientific evidence are recommended.

Recommended guidelines for improving recovery and outcome of training

- Only the assigned physiological or physical characteristics that are targeted during the overreaching period should be excessively stressed, while a minimum of training load and stress should be generated on all other physiological characteristics.
- Plan your training in microcycles of 1 week or similar entity and include at least 1 day with complete recovery in the cycle.
- After periods of targeted training emphasis (over-reaching periods) of 2–5 weeks include a recovery period of at least 2–3 days in the training programme.
- Include recovery exercises to the training programme; such exercises are low-intensity short duration (20–30 min) exercises including sprints, gymnastics, snow-walking, light strength exercises such as jumps, etc.
- Practise sufficient warm-up, warm-down and stretching.
- Practise variation and periodization in your training.
- Use alternative training modalities if mild overuse symptoms occur.
- Consider massage, hydrotherapy or other local musculoskeletal therapy for some muscles.
- Consult a sports physician or physical therapist if local musculoskeletal symptoms persist.
- Regularly control your training state.

The importance of recovery exercises was presented in Chapter 3 (see section on Training, Table 3.5). In that example, national ski team and junior ski team members were divided into two groups. The ‘quality’ group replaced the last 30–60 min of their low-intensity distance training sessions by running, snow-walking, short sprints, jumps and stretching. After the November volume-training period the $\dot{V}O_{2max}$ had increased significantly in the ‘quality’ group while the ‘normal’ November training had no effect on $\dot{V}O_{2max}$.

As an example of the emphasis on only one targeted characteristic, one may intentionally challenge the body’s ability to burn more fat relative to glycogen by performing 3–4-h sessions of low-intensity skiing without food intake. However, it should be done with plenty of fluid intake during the exercise so that detrimental effects of large fluid losses can be avoided.

Decreasing the total stress

Identifying the most common non-training stressors

Several non-training stressors can have a negative impact on recovery and thereby the improvement in performance. Each athlete has a limit to how much total stress he or she can tolerate and cope with without detrimental effects. Thus, the more unnecessary non-training stress that can be eliminated, the greater total training load can be tolerated and the better adaptation to training will be.

Non-training stressors are dependent on physical environment (temperature, humidity, altitude–oxygen content, time zone shift), psychosocial environment (personal, interpersonal and situational factors), primary and secondary needs (rest, sleep, nutrition, sex), physical and mental state before training (see Chapter 6, Psychology), etc. However, which stressors affect the skier most and the respective countermeasures of recovery may vary considerably from one skier to another. Therefore it is important to identify the *most common* conditions and situations that affect the quality and/or quantity of recovery before, during and after training sessions. Both the list of common stressors and the list of corresponding recovery measures given below are based mostly on field experience with international skiers over a number of years. Some of the guidelines are backed up by scientific evidence. However, there is a general lack of investigations on the effect of several recovery measures on different variables of performance in elite athletes (Fig. 5.6).

Ten most common non-training stressors that may disturb recovery after training

1 Cold weather and wind resulting in reduced body temperature.

2 Heat and high humidity resulting in increased body temperature.

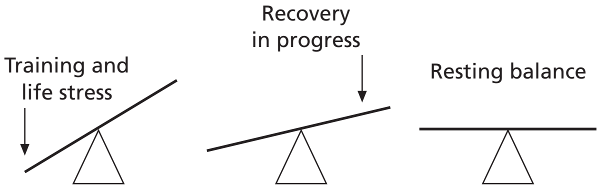

Fig. 5.6 After completing a training session, the speed of recovery will be determined by the magnitude of training and non-training life stresses. If the next session is started before complete recovery is achieved, fatigue starts to accumulate (see Fig. 5.1). If training and non-training life stresses are increased, a balance must be sought by improving the recovery measures.

3 Dehydration resulting in body weight loss of > 2%.

4 Caloric deficiency, with low intake of carbohydrates proteins and/or fat.

5 Micronutrient deficiency with low intake of vitamins and minerals.

6 Sleep deficiency and generalized fatigue.

7 Travelling stress and 'jet-lag' problems.

8 Psychological stress and mood disturbances.

9 Social instability and disruptive lifestyle.

10 Somatic illnesses such as anaemia, allergies, asthma, common colds, etc.

Having identified these categories of stressors the important task is to reduce and eliminate as many stressors as possible. Particularly when athletes are undertaking two training sessions per day, the strategies for optimal recovery become paramount because of the limited time between each session. When daylight is limited to 6–8 h·day^{-1} in late autumn and early winter, cross country skiers may have only 3–4 h of recovery between the end of the morning training session and the beginning of the afternoon training session. During this period with large training volumes the training effect can be inhibited, in spite of the great quantities of training, without proper enhancement of recovery (Figs 5.1 and 5.5).

Strategies for decreasing non-training stress

Effective recovery starts with proper preparation *before* the training session begins. The general principle of '*prevention being superior to treatment*' in medicine also applies to this area of sports. It is beyond the scope of this chapter to go into detail on the various recovery measures suggested below. The intention is to bring the different issues of recovery to the reader's attention and generate awareness on how systematic stress reducing and recovery enhancing regimes may contribute to improved adaptation to training. It is advisable that each skier (and coach) should run through this checklist and, on the basis of the individual lifestyle and training schedule, evaluate which measures of recovery he or she needs to improve on.

1 Avoid extreme cooling.
  (a) Use proper clothing which allows transportation of heat and sweat from the skin and protects against the cooling effects of wind from the outside.
  (b) Bring an extra set of dry underwear for change immediately after competitions or training.
  (c) Dry off body sweat before changing to dry underwear.
  (d) Allow 10–15 min 'warm-down' after competitions or intensive training.
  (e) Use breathing protection/heat exchangers when exercising at temperatures <–10°C.

2 Avoid overheating on hot days.
  (a) Minimize direct exposure to sun before, during and after training.
  (b) Use white and light clothing if training in the sun.
  (c) Drink plenty of fluid, preferably as cold as you can tolerate.
  (d) Avoid hot rooms and environments the first hour after training.

3 Avoid dehydration.
  (a) Drink as much as you can tolerate before each training session.
  (b) While exercising, start drinking before you get thirsty.
  (c) During moderate and high intensity training drink at least 0.5–0.7 l·h^{-1}.
  (d) If more than 60 min sessions, use 5–7% carbohydrate–electrolyte solutions.
  (e) If major dehydration (>3% reduction in body weight), use hyperosmolar solutions and add extra table salt on food.
  (f) When at altitude, increase daily fluid intake with 1 litre per 1000 m elevation.

4 Avoid caloric deficiency.

(a) Have 3–5 regular meals per day of various food choices containing approximately 65–70% carbohydrates, 25–30% fat and 15% proteins of the overall daily intake.
(b) Do not start training on an empty stomach; have a small snack 1 h before training.
(c) Eat a sandwich or an energy-bar after training if there is no meal within 1 h.
(d) Take plenty of time to eat the meal; do not eat too fast.
(e) Monitor your body weight, it should not alternate > 3% from your 'match weight'.

5 Avoid micronutrient deficiency.
(a) Eat a well-balanced diet with cereals, bread, vegetables, fruits, seafood, pasta, rice and, preferably, white meat.
(b) Use mostly fresh foods, rich in vitamins and minerals and prepare carefully.
(c) Check iron status and start iron intake a few weeks before undertaking altitude training.
(d) A moderate dosage vitamin and mineral supplement may be recommended if:
- specific deficiencies are diagnosed;
- on a temporary low caloric diet;
- illnesses and conditions with reduced appetite;
- periods with altitude training; and
- travels with major changes in food choices.

6 Avoid sleep deprivation and fatigue conditions.
(a) Have organized sleeping patterns, including sleep before midnight.
(b) Rest in bed/sleep for 1 h in the afternoon if two training sessions per day.
(c) Check your indoor environment for air quality and potential allergens.
(d) Take a day off and discuss with coach if progressive tiredness arises.
(e) Consult a sports physician if unexplained fatigue persists >1 week.

7 Minimize travel stress and jet-lag problems (see next section).
(a) Plan for the most convenient travel schedule to your destination.
(b) If crossing several time zones, adjust 2 h the last days before leaving.
(c) Synchronize your activities to new local time on the day of travel.
(d) Avoid long-term passivity during travel, include light exercise and stretching.
(e) Stay synchronized to new sleep, meal and activity schedule after arrival.
(f) Schedule training sessions to local hours corresponding to daytime at home.

8 Minimize negative psychological stress (see separate chapter 6).
(a) Have realistic expectations and goals for your athletic career.
(b) Stick to your own priorities and do not try to succeed in all aspects of life.
(c) Face the problems and conflicts when they appear, but do not look for them.
(d) Stay involved in activities outside your sport with non-athletes.
(e) Talk to someone in the team if mood disturbances persists, conflicts continue and psychological problems progress.

9 Minimize social instability.
(a) Make a season plan for school, job, economy, travels, sponsor obligations, etc.
(b) Avoid changing places to live and friends/partners to live with too often.
(c) Do not make your private life unnecessarily dependent on other peoples' goodwill.
(d) Do not compensate strict training schedules with excessive 'social' life.

10 Minimize risk for episodes of illnesses (see Chapter 4).
(a) Avoid triggering factors for allergies and asthma.
(b) Use medications as prescribed if you are under treatment.
(c) Avoid unnecessary contact with infectious people.
(d) Practise good standards of hygiene, both individually and in the team.

A complete recovery plan must take into consideration both training and non-training stressors in order to create the best opportunity for successful regeneration and adaptation to the training. However, effective recovery measures should never be a substitute for hard training. Recent advances in the control of the training state (see above) will help the athlete, coach, team physician and medical staff to evaluate more closely when the athlete is presenting signs and symptoms of insufficient recovery or symptoms of illness and injury. By teaching athletes to practise these and other basic routines of recovery, they can increase their tolerance for hard training and also prevent health problems associated with overtraining.

Main points to remember about overreaching and recovery

- Training effect depends on the balance between total training and non-training stress vs. quality and quantity of recovery measures.
- Only the assigned physiological or physical characteristics that are targeted during the overreaching period should be excessively stressed, while a minimum of training load and stress should be generated on all other physiological characteristics.
- Implementing improved measures of recovery from training stress is an effective way of improving tolerance for and adaptation to the total training load as well as preventing health problems and overtraining syndrome.
- A complete recovery plan must take into consideration both training and non-training stress. A general guideline is to keep non-training stress to a minimum so that the body can direct most of its 'energy' towards recovery from training stress.
- The most common non-training stressors for a skier are related to physical environment (temperature, humidity, altitude–oxygen content, time zone shift), psychosocial environment (personal, interpersonal and situational factors), primary and secondary needs (rest, sleep, nutrition, water balance, macro- and micronutrients, sex), physical and mental state before training, illnesses and injuries.
- Orthostatic heart rate test is a simple field measure to control the training state (the training and non-training stress as well as the recovery).
- Effective recovery measures are not a substitute for hard training, but optimal regimes can and will make the athlete benefit more from the training.

Adjustments to travelling across time zones

Circadian rhythms

World-class skiers often travel to several continents and across many time zones for training and competitions. It is generally suggested that if more than 3–4 time zones are crossed, certain biological functions are disturbed and temporary impairment in performance may arise. It is therefore important for a skier to know what biological (physiological and mental) functions undergo rhythmic changes and influence performance (Fig. 5.7).

Fig. 5.7 Changing the time for sleep to the night hours at local destination time is one of the most important measures to achieve rapid time adjustment. In practical terms this may imply dark sunglasses and earplugs to shut out light and sound in order to sleep at a new schedule.

The menstrual cycle is a biological rhythm and normally has a 28–30-day periodicity. Another biological rhythm is the change in body temperature from a morning low of approximately 36.5°C to a peak of approximately 37.5°C in the evening. This rhythm has a cycle of 24 h and is therefore referred to as *circadian* rhythm, from the Latin *circa diem* meaning about 24 h. There are many biological functions that have circadian rhythms.

Biological functions with circadian rhythms

1 Body temperature–rectal temperature.

2 Cardiovascular—heart rate, blood pressure.

3 Respiratory—ventilation rate, forced expiratory volume and peak expiratory flow.

4 Metabolic—oxygen consumption.
5 Gastrointestinal—gastric pH and emptying, intestinal motility and absorption.
6 Hormonal—adrenaline, noradrenaline, cortisol, growth hormone, testosterone, thyroxin, melatonin, etc.
7 Psychological—wakefulness, alertness, fatigue and other mood states.

Circadian rhythmicity is influenced by both internal and external factors. The most important internal 'governor' is the 'body clock' in the hypothalamus region of the brain. The hypothalamus influences the bodily functions through the autonomic nervous system and hormone secretion. However, external factors such as light and darkness, temperature, visual and auditory input, meals and physical activity are also important regulators of biological rhythmicity. It is not fully understood how environmental and behavioural factors influence biological rhythmicity. So far it has been shown that both neural and hormonal changes from variations in light, physical, mental and social activity, have an input on the biological clock of the brain. For example, the change between light and darkness during a 24-h cycle has a direct impact on concentration of the hormone melatonin secreted by the hypothalamus, which governs wakefulness and sleep. Thus, biological functions that follow circadian rhythmicity undergo regulation from both our interior and exterior milieu and there is a two-way communication between the internal biological clock and the external environment.

The essence of circadian rhythms is that during long distance travelling across time zones the biological functions will follow the 'body clock' of home setting and not the 'time clock' of the new location. The extent of this desynchronization between 'body clock' and 'time clock' is dependent on how many time zones are crossed and how fast one is travelling.

'Jet-lag'

The problems (signs and symptoms) associated with desynchronization between the 'body clock' and 'time clock' caused by air travel over several time zones has been named 'jet-lag'. Travelling in eastward or westward directions can cause different problems. *Westward* travelling usually happens during daytime and results in an extension of the day with a certain number of hours before going to bed in the evening at the new local time. Waking up next morning is not difficult, because it is late morning according to 'body clock'. The main problem is sleepiness in the afternoon and evening in the new destination.

Most long distance travel in an *eastward* direction implies spending a short night on the plane, often with a minimum of sleep. Starting the next morning at an hour corresponding to bedtime at home with little or no sleep during the night often results in considerable discomfort and tiredness during the next few days.

Signs and symptoms associated with jet lag
1 General feeling of malaise and discomfort.
2 Fatigue during parts of the day and wakefulness during parts of the night.
3 Disturbed appetite, digestive problems, nausea and headache.
4 Disturbed mental functions such as concentration and vigilance.
5 Decreased psychomotor functions such as balance and coordination.
6 Decreased endurance capacity and stamina.

The problems associated with 'jet-lag' can vary from one skier to another and there may also be different signs and symptoms, as indicated above. A rule of thumb is that the problems should not last for a greater number of days than the number of time zones crossed: complete acclimatization to 8 h difference in local time should not take longer than 8 days. Anyone having experienced a change in time of 8 h or more, going east or west, has learned that the first 2–4 days are the worst. From the list of symptoms one can easily understand that most sport performances can be affected by travelling across several time zones. Reaction time, muscle strength, submaximal work capacity, lactate production, joint mobility and long-term memory have been shown to be disturbed. Especially in those sports where concentration and fine motor skills are crucial, the athlete's performance may be impaired by jet-lag.

The order of acclimatization is the following: first the sleep–wake cycle is normalized, then body temperature sychronizes to follow the rhythm of the new time, followed by disappearance of jet-lag symptoms and, finally, performance rhythms start to follow the diurnal rhythm of the destination. The

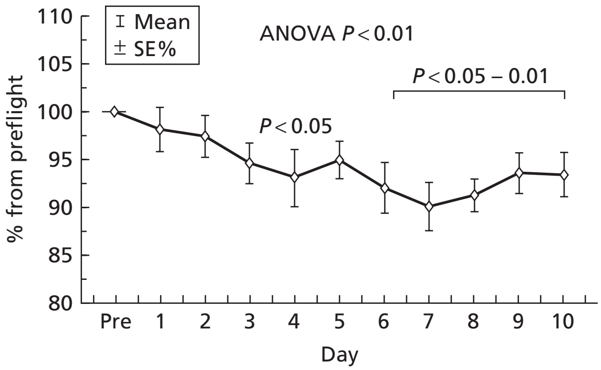

Fig. 5.8 Morning parasympathetic (PNS) activation has not returned to preflight values in 10 days after a 22 h eastward flight across nine time zones. Index of parasympathetic activation was calculated from supine heart rate, peak heart rate after standing up and high frequency power. 100% denotes the level of activation before the flight. More demanding training started after 5–6 days and may have influenced the index during the consecutive mornings. (From Rusko *et al.* 2000.)

latest findings on elite athletes have shown that, despite the subjective feeling of sleeping well, movements during the night are increased and sleep quality is impaired even 1 week after arrival at the new destination and crossing several time zones. Similarly, PNS activation (and ability to recover) had not returned to pretravel level in 10 days (Fig. 5.8).

Optimizing acclimatization

How can the skier alleviate and minimize the problems of jet-lag and train or compete at an optimal level as soon as possible? A list of common guidelines gathered from the scientific literature is presented, especially as an aid to relatively inexperienced travellers. The guidelines are assuming a change in time of 6 h or more.

Guidelines for long distance air travel across >6-h time zones

1 Before the flight

- Schedule the arrival date at the new location several days prior to the first day of the competition. (Eastward: 1 day for each hour change. Westward: 0.5–1 days for each hour change.)
- Try to find the most convenient flight schedule, preferably a direct flight to the destination, or a minimum of stopovers, especially if travelling at night.
- During the last 4 days before departure try to adjust 2 h towards the new local time; approximately 0.5 h·day^{-1} earlier mornings (eastward) or later nights (westward).
- Get plenty of sleep the night before departure.
- Eat and drink well before the flight. Bring your own food and water if you do not like the airline food and drink.

2 On the flight

- Set your watch to local destination time as soon as possible and synchronize your meal and sleeping pattern on the plane to local time.
- Drink plenty of fluids, but avoid drinks with alcohol, caffeine and tea, which have a dehydrating effect.
- If starting the flight when the local destination time shows late night or early morning, try to get a short nap at the beginning of the flight.
- If flying during the daytime or evening, get up and move around as much as possible and include some stretching.
- Use of surgical stockings and/or elevation of legs may prevent swelling and oedema.
- If starting the flight when local destination time shows late evening, try to get a carbohydrate-rich meal before going to sleep. Sleeping pills may be taken if prescribed for you by the team physician.
- Do not go to sleep when feeling drowsy if the local time shows daytime.

3 After arrival

- Stick to the schedule of synchronizing your body clock to local day and night time routines, including sleep, meals, physical activity and training.
- A short sleep before noon may be taken if arriving in the early morning after an eastward flight; otherwise, no extra naps during daytime.
- A carbohydrate-rich meal is recommended 1–3 h before going to bed on the first day.
- Use the *daytime* hours that both body clock (home time) and local time have in common as time for training on the first few days (late evenings if moved 8 h east and mornings if moved 8 h west).
- Bright light in the room in the morning (going eastward) or evening (westward) is recommended. Special light therapy can also be helpful when performed at

the correct hours, but should only be used in close cooperation with special therapists.

Melatonin

Melatonin is a hypothalamic (brain) hormone and its secretion is influenced by light and darkness in our environment. It peaks during the night and regulates the sleep–wakening cycle of the body, but is also involved in other physiological functions mainly as an antioxidant. After discovering its time-regulating abilities, it has been commercially produced and made available as a nutritional supplement or prescription drug. Even though it may be sold over-the-counter in some countries, it is recommended that athletes only use it under the supervision of a (team) physician. One reason is the potential side-effects that may arise (nausea, headache, etc.); another is the concern for contamination with IOC banned drugs. Normally, it is taken when darkness arrives at the new local destination, usually between 20:00 and 22:00. If embarking on an eastward journey, melatonin could be taken before boarding the flight (corresponding to evening/night time local destination). After arrival in the east, it should be continued for the next 6–8 nights if eight time zones have been crossed, and 8–10 nights if even larger time leaps have been made.

When travelling westward—which normally means daytime at the local destination—melatonin should not be used during the flight. After arrival and change to local time, tiredness is quite evident when evening comes and most people go to sleep very easily. However, waking up too early the next morning is quite customary, and therefore it might be wise to take melatonin *immediately* before going to bed on the first night. The purpose of this is to supply the brain with its 'night' hormone at the time when its own hormone production is turning down because it is morning in the home country. The supplemented melatonin will then provide high levels in the brain during the night at the new location and thus provide sleep for a little longer in the morning. The number of nights that melatonin is recommended varies, but generally it may correspond to the number of time zones crossed minus two.

The scientific basis for using melatonin to reduce jet-lag symptoms is fairly solid, but from clinical experience there is a definite history of responders (those who benefit) and non-responders (those who do not benefit). This means that an individual approach has to be taken for each athlete, including a close follow-up on the course of time adjustment as well as possible side-effects. The impact of melatonin on performance is not well documented; however, the rationale is that if melatonin reduces some of the mental and physical problems associated with jet-lag, it will positively affect training quality and, ultimately, sports performance during the acclimatization period.

Travelling back home

So far we have focused on adjustments to travel from 'home base' to an eastbound or westbound destination for training camps or competitions. The inevitable fact is that some day a *return journey* to 'home base' must take place. This must be planned and executed with the same optimal travel routines as the outward journey. For the most part, it simply means that the guidelines of going in the *opposite* direction of the outward journey must be applied. Nevertheless, it is a common experience that both team staff and athletes have a tendency to 'take out the slack' when returning home and disregard many of the guidelines of time adjustments. If there is limited time for effective home base training, it is wise to comply with the established routines—both on the return flight and the following days at home. As athletes may be exceedingly stressed and tired after a hard training camp or series of competitions, it might also be wise to ensure that the necessary measures of preventing infections and improving recovery are taken on the return journey. Additional travel stress and exposure to infectious sources through new people and places—while the immune system might be suppressed—could easily result in a respiratory infection after returning home. Therefore, implementing a good strategy for travel routines and time adjustments when going home is as important as when travelling to an event.

Main points to remember about travelling across time zones

- It is generally suggested that if more than 3–4 time zones are crossed, circadian rhythmicity and certain biological functions are disturbed and temporary impairment in performance can arise.

- Most circadian rhythms are governed by the hypothalamus region of the brain. However, external factors such as light and darkness, temperature, visual and auditory input, meals and physical activity also influence the 'body clock'.
- Examples of circadian rhythmicity (roughly 24-h cycles) are: body temperature, heart rate, blood pressure, ventilation rate, oxygen consumption, gastric emptying, intestinal motility, mood states (such as wakefulness, alertness, fatigue) and hormone production (cortisol, growth hormone, testosterone, thyroxin and melatonin).
- 'Jet-lag' is a condition associated with desynchronization between the internal 'body clock' and the external 'time clock' and it typically induces malaise, fatigue, headache, loss of appetite, as well as decreased concentration, balance, coordination and endurance capacity.
- Optimizing time acclimatization should involve actions taken before, during and after a flight to a new destination including pretravel time adjustment, diet and drinks, physical activity, regulation of exposure to light and sleeping patterns, possibly involving sleeping pills and melatonin.
- Athletes should only use sleeping pills and melatonin under the supervision of a physician.
- Guidelines for time adjustments are as important when going home as when travelling to an event.

Haemoglobin tests, erythropoietin and doping control

The beneficial effect of increased red blood cell volume either by heterologous blood transfusions or injections of recombinant human erythropoietin (rhEPO) on aerobic performance has been demonstrated in several studies during the last 50 years. Since the 1970s there have been rumours about the use of blood doping and in one case there is official evidence of the use of blood transfusions in ski sports. In 1988 the International Ski Federation (FIS) decided to begin to control for blood doping by testing for blood transfusions at the 1989 World Ski Championships. This also gave FIS an opportunity to follow the development of individual and mean haemoglobin (Hb) concentrations among skiers.

In 1989, when post-race blood samples were taken for the first time to detect heterologous blood transfusions, Hb values were similar to the reference values for the normal population. The mean ± SD Hb concentration after the race was 148 ± 8 g·l^{-1} for men and 135 ± 7 g·l^{-1} for women skiers, and the corresponding highest individual values were 165 and 149 g·l^{-1}, respectively.

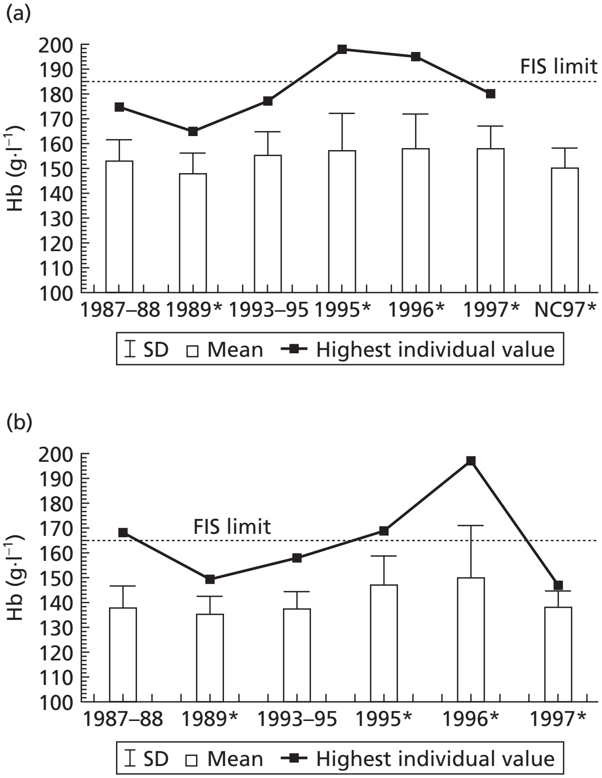

Fig. 5.9 Development of mean (±SD) and individually highest haemoglobin concentrations of (a) men and (b) women world-class cross country skiers, 1987–97. Most blood samples were taken after World Cup or championship ski-races (*). The means and the individually highest values have increased until 1996 after which the pre-race haemoglobin test was started, inducing a decrease of the means and individually highest values below the upper limits defined by the International Ski Federation (FIS) (solid line). In (a), data from Nordic combined skiers in 1997 have been included. (Modified from Videman *et al.* 2000.)

The follow-up of the post-race blood data in the 1990s revealed that the mean Hb concentration and, in particular, the individual maximal Hb concentration had begun to drift upwards, suggesting that rhEPO was being used to increase Hb concentration artificially (Fig. 5.9). It is well known that polycythaemia increases markedly the risk for blood clots, which can lead to fatal complications such as strokes, heart attacks and pulmonary emboli. The International Olympic Committee (IOC) has documented several deaths among cyclists with supraphysiological red cell mass and haemoglobin values, indicating that there was an obvious need to do something to decrease the medical risks involved and limit the possible use of rhEPO and, possibly, autologous blood transfusions. Consequently, these methods are considered unethical and have been made illegal in all sports.

However, there are several unresolved problems related to methods for detecting the use of autologous blood transfusion or rhEPO. During the first years after rhEPO came into clinical use in the 1980s, there were no methods available to demonstrate its use. Today the use of rhEPO can be detected, but the fast elimination rate of the EPO still produces major practical difficulties in attempts to disclose its use. The most sensitive methods today can detect it for about 1 week from its administration, but the red blood cells produced by the artificial rhEPO are alive for several months, which makes rhEPO an 'ideal doping agent'. If rhEPO is used extensively for 3–4 weeks it increases the total volume of red cell mass and haemoglobin mass, $\dot{V}O_{2max}$, and skiing performance for a period of another 3–4 weeks, while the actual drug will have left the body completely within 1 week of the last injection. This leaves a 2–3 week 'open window' where skiing performance is enhanced and there is no drug present. Standard doping control procedures are based on detecting the banned drug in the body of the athlete, thus detection of this substance has been very difficult under the present doping control procedures.

Recently, a protocol to deter and detect the use of rhEPO was tested out in the Olympic Games in Sydney and Salt Lake City. It consisted of both a blood and a urine test. In addition to the Hb level, the blood test indicates the presence of accelerated, normal or inhibited erythropoiesis. The blood test does this by measuring the size and number of reticulocytes, the level of EPO in blood and the level of soluble transferrin receptor (sTr) in blood. The urine test can differentiate between rhEPO and natural EPO because rhEPO is made in cell cultures that use different sugars compared to natural EPO from human kidney cells. As rhEPO and natural EPO are coated with different sugars on their surfaces, the molecules have different electric charges and can therefore be distinguished.

Pre-race haemoglobin testing

There is considerable variation in Hb concentration among both athletes and non-athletes. Therefore, it is obvious from statistical evidence that 'abnormally' high Hb concentrations are not enough to demonstrate that an individual has used 'blood doping'. In this situation a new strategy was adopted: FIS made a ruling relating to Hb values (1996): 'Skiers whose haemoglobin values are higher than the mean value (of men or women) added with 3 standard deviations will not be allowed to participate in FIS organized ski races.' Additional details to this rule were that the possible exclusion of a skier with too high a Hb concentration was related only to the competition in question and would not lead to any sanctions. Further, skiers with too high Hb values should be advised to get adequate treatment for their polycythaemia, which involves increased health risks (see above). An underlying principle was that it did not matter what was behind the high Hb values: use of rhEPO, low oxygen pressure at high altitude, or artificial environment ('altitude house' with increased concentration of nitrogen and decreased oxygen concentrations) or genetics, they all increase the health risks if they increase Hb concentration.

Pre-race Hb concentration is influenced by several factors that may change plasma volume. Plasma volume is influenced by hydration status, prior exercise, body position during blood drawing, how long a tourniquet has been applied and, in particular, by altitude changes. During exposure to altitude there is an early rapid reduction in total plasma volume resulting in a short-term increase in Hb (see section on Altitude training). As the acclimatization process proceeds, plasma volume is partly restored but not completely to normal levels. After return to sea level, a further increase in plasma volume occurs, often to higher levels than before the altitude training or racing. Usually, this increase in plasma volume is equal to the increase in the number of circulating Hb molecules and red blood cells, and the Hb concentration ($g\ Hb \cdot l^{-1}$ blood) will be unchanged from before to after the altitude period.

In 1996, the first limits set by FIS were 185 $g \cdot l^{-1}$ for men and 165 $g \cdot l^{-1}$ for women, based on population norms plus 3 SD. However, as of the 2000–01 season, the limits have been lowered to 175 $g \cdot l^{-1}$ and 160 $g \cdot l^{-1}$

for men and women, respectively. As with any testing procedure, knowledge was gained as the pre-race Hb test was used and subsequent refinements were made. The initial problems concerning athlete selection criteria, timing of the announcements, proper facilities for testing and standardization of the procedures for blood drawing and Hb analysis have been resolved. Today, Hb concentrations are sampled by random selection of athletes in the 2 h prior to the race. They are measured from venous blood drawn and analysed on a Hemocue photometer in the presence of the athlete.

There has been some controversy over the limits for Hb concentrations used by FIS. The first limits of 185 $g \cdot l^{-1}$ and 165 $g \cdot l^{-1}$ were relatively high Hb concentrations for endurance athletes, thus possibly leaving 'room for cheating' below the Hb concentration limits. However, after lowering the limits to 175 $g \cdot l^{-1}$ for men and 160 $g \cdot l^{-1}$ for women, there may be a problem of excluding athletes with genetically high levels of Hb, particularly if they are training and competing at altitudes of 1500–2000 m. Another concern regarding Hb testing has been the conditions under which the blood is drawn. Total plasma volume, as mentioned above, is not completely stable and a change in plasma volume will alter the Hb concentration in the blood. If the athlete has recently ascended to altitude, has had an infection, is particularly nervous or aggravated, or if the athlete is not seated or laid down properly before the blood test, the measured Hb concentration may be artificially high. Also, if an athlete has too high a Hb concentration prior to the official testing, it is possible to 'dilute' the haemoglobin concentration by intravenous administration of saline. It must be emphasized that infusion of any kind of plasma expander including saline is a prohibited means to decrease Hb concentration before pre-race testing. Further, plasma volume expansion alone may increase performance of an elite athlete. To avoid any problems with the pre-race Hb testing the athlete should be properly advised about correct preparations and procedures.

The present control system of pre-race Hb testing and post-race blood and urine doping testing has raised the question of whether only a post-race blood sample could be used and whether the post-race Hb concentration is different from the pre-race value. If a blood sample is taken 15–60 min after the race (normal time range for doping test) the water loss during the race does not appear to increase Hb concentration and Hb concentration is probably lower than before race (Fig. 5.10). This indicates that haemoconcentration and plasma volume decrease during the race are well recovered 15 min after the race. Even in a situation with no fluid replacement before, during or after the race (or exercise), Hb concentration is the same or lower after the race compared to the pre-race value.

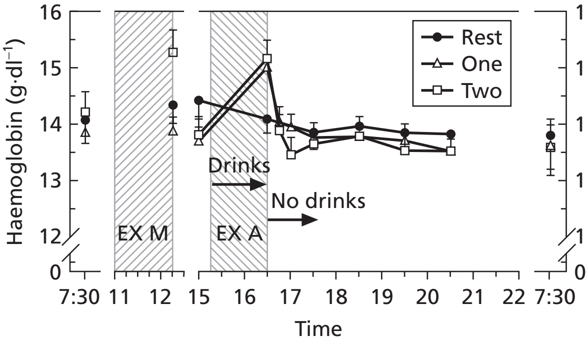

Fig. 5.10 Haemoglobin values before and after 75 min of intense exercise in the morning (EX M) and afternooon (EX A). Group Two carried out both exercises, Group One on EX A and Group Rest served as control. (From Ronsen *et al.* 2001.)

Advice to the athlete undergoing pre-race haemoglobin testing

1 Be well hydrated several hours prior to testing.

2 Be well rested physically and mentally.

3 Bring your own physician or other personnel familiar with Hb-testing.

4 Remove any tight fitting clothing around the arm for venepuncture.

5 If possible, lay down for 5 min before your blood is drawn.

6 Make sure that an adequate sample (3–5 ml) is collected in a purple top tube.

7 If the first value is abnormal, ask the staff to repeat the assay from the same tube.

8 Have the staff recalibrate the Hemocue in front of you.

9 Rest in a supine position for 10 min before the next sample.

10 Always have your own medical staff present for the second test.

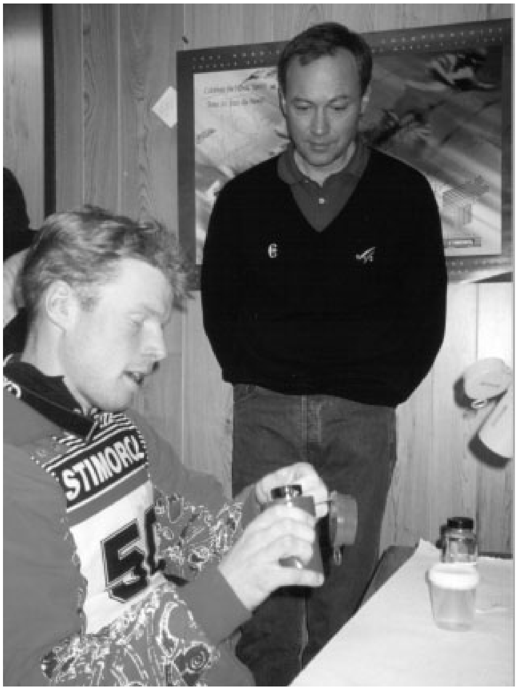

Fig. 5.11 Doping controls serve a dual purpose of deterring athletes from getting involved in illegal performance enhancing activities as well as detecting 'cheaters'. It is important to teach the athlete how proper routines should be carried out, both on behalf of the controllers and the athlete. This will reduce the risk of procedure problems with both blood and urine samples.

Doping control: responsibilities and rights

It must be emphasized that all relevant information from FIS and national sports federations about all aspects of doping (medications and methods used to improve performance artificially) should be given to the athletes and coaching staff by the team physician. This includes the procedures for regular doping control and the *responsibilities* of the athlete to perform this control in a correct way. Signing the initial notification and appearing at the doping control office within the time limit of 1 h is very important. The athlete must also be informed that if he or she refuses to provide a sample, regardless of possible disputes over the procedures of the control, it is considered equal to a positive test. However, the athlete should also be informed about his or her *rights* during the doping control, including correct identification of the doping officials, provision of facilities with proper privacy and approved and sealed equipment for the samples.

It is not possible to give a detailed description of how a regular doping control is supposed to be carried out, but the athlete and accompanying person should pay close attention to the numbers on the A and B urine or blood containers. Review all the information that the officials are putting down on the doping control form and be careful to list all medications and nutritional supplements that have been used during the last week prior to the testing. New athletes in the team should always have a knowledgeable physician to accompany them to international doping controls. If possible, a health staff member should also accompany all other athletes to ensure that all procedures are being carried out correctly. There may be some discrepancies between rules of national ski federations, FIS and IOC regarding the regulation of some types of medications, as well as in some of the procedures/equipment used in the post-race doping control. Thus, it is important both for the team physician and the athletes to be aware of such differences and know which competitions are regulated by which organization.

Athletes should be taught to check with the team physician before any medication or supplement is taken, whether prescribed or over-the-counter. No athlete should carry medication across national borders without the knowledge and approval of the team physician. Finally, it is important to stress that, ultimately, it is the athlete who is responsible for whatever he or she chooses to take, either as medication or nutritional supplement. Athletes should know all the relevant doping rules and regulations in their sport and abide by them.

Main points to remember about haemoglobin tests, erythropoietin and doping control

- In 1989, FIS was the first sport organization that started to take post-race blood samples to detect heterologous blood transfusions and to measure the Hb concentration of individual skiers.
- In 1996, FIS made a decision to take pre-race blood samples to exclude men with Hb >185 $g \cdot l^{-1}$ and women with Hb >165 $g \cdot l^{-1}$ from participation in the race for health reasons.

- In 2000, FIS decided to reduce the pre-race limits of Hb to 175 $g \cdot l^{-1}$ for men and 160 $g \cdot l^{-1}$ for women.
- In 2000, IOC decided to introduce a urine test for rhEPO and a modified blood test for Hb, reticulocytes and transferrin receptors in the Sydney Olympic Games and the same protocols were applied in the Salt Lake City Winter Olympic Games.
- The two main reasons for introducing Hb limits for race participation are:
  1 to protect the health of the athlete; and
  2 to minimize the extent of unfair advantage gained by blood doping methods.
- To avoid problems with the pre-race Hb testing the athlete should be properly advised about correct preparations and procedures for the testing.
- Relevant information from FIS and national sports federations about all aspects of doping (medications and methods used to improve performance artificially) should be given to the athletes and coaching staff by the team physician.
- The athlete should know the responsibilities and the rights connected to the procedures of FIS doping controls, but an experienced team physician should accompany all new athletes in the team to international doping controls.
- Ultimately, it is the athlete who is responsible for the intake of all medications and nutritional supplements. Athletes should know all the relevant doping rules and regulations in their sport and abide by them.

Altitude training and simulated altitude training

Cross country ski-races are held at altitudes of up to 1700–1800 m and during summer it is possible to have ski-training camps on snow at altitudes of 2000–3000 m with a lower living altitude of 1000–2000 m. Therefore, training at medium altitude is an essential part of the training schedule of successful cross country skiers. In the last 20 years, $\dot{V}O_{2max}$ of athletes in different sport disciplines including cross country skiing has increased, and world records in distance running have improved. Altitude training has been perceived to explain most of the changes because athletes living and training at altitude have won most of the Olympic medals in distance running in 1992–2000.

In addition to the summer ski-training camps, the goals of altitude training are:

1 acclimatization to altitude before important races at medium altitude; and

2 to use altitude training to improve race performance at sea level or at low altitude.

The development of new methods to simulate altitude introduced the new possibility of:

3 using simulated altitude training at sea level for preparation for altitude training camps, for ski-races at medium altitude and for ski-races at low altitude or sea level.

Several studies have shown that altitude training improves $\dot{V}O_{2max}$ and performance at altitude, and there is also evidence that it is helpful for sea level performance.

Acclimatization and training at medium altitude

Effects of acute hypoxia

Altitude is a hypobaric environment in which the atmospheric pressure is reduced while the concentration of oxygen is the same (about 21%) as at sea level, and thereby the partial pressure of oxygen (P_iO_2) in the inspired air decreases. This lowers the oxygen content of blood which is probably one of the most important variables that influences performance and adaptation (see Chapter 1). In elite endurance athletes the oxygen saturation of blood (S_aO_2) is decreased even at sea level and therefore even a small decrease in P_iO_2 further decreases S_aO_2 (see Chapter 1, Fig. 1.2). $\dot{V}O_{2max}$ of elite cross country skiers is sensitive to the lowering of S_aO_2 and the oxygen content of blood, and the $\dot{V}O_{2max}$ of endurance athletes is significantly decreased even at altitudes of 600–900 m, whereas sedentary people experience a decrease in $\dot{V}O_{2max}$ at altitudes of 1200–1500 m (Fig. 5.12); the decrease seems to be greater the higher the $\dot{V}O_{2max}$. Therefore, cross country skiers are recommended to use altitude training for preparation to ski-races both at sea level and at low altitude.

An acute response to decreased P_iO_2 and oxygen content is an elevation in haemoglobin concentration within 1–3 days after ascent to altitude because of a decrease in plasma volume. The haemoglobin concentration remains elevated and plasma volume decreased during the altitude training period, despite a slight reincrease in plasma volume. Another acute response is the increase in pulmonary ventilation (breathing) both at rest and especially during exercise. As a consequence, CO_2 is reduced and respiratory alkalosis develops. To compensate for this the kidneys excrete more bicarbonate and the buffering capacity of

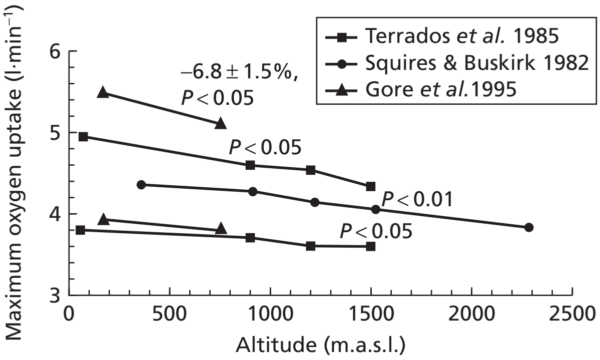

Fig. 5.12 $\dot{V}O_{2max}$ of elite athletes is acutely decreased at altitudes lower than 1000 m. The decrease seems to be greater the higher the $\dot{V}O_{2max}$. Less fit persons demonstrate a decrease at higher altitudes.

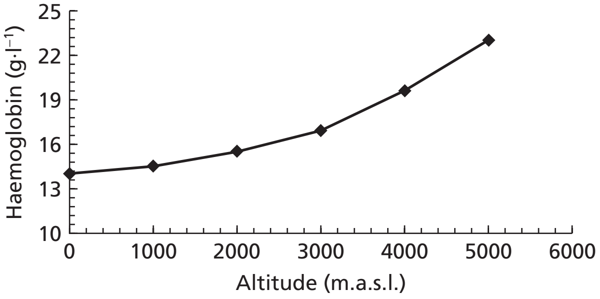

Fig. 5.13 Haemoglobin concentration in acclimatized people living at different altitudes.

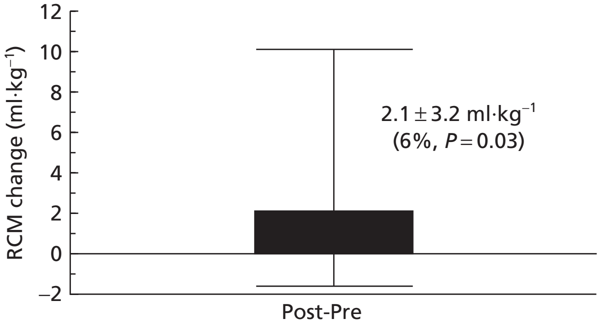

Fig. 5.14 Mean (±SD) and individual range of red cell mass (RCM) increase in 14 elite distance runners after training for 4–5 weeks at altitude of 2200–2300 m. Some athletes may have problems increasing their RCM, probably because of poor iron status or wrong training at altitude.

blood is decreased at altitude. Other acute changes can be ascertained from textbooks.

Acclimatization to chronic hypoxia

The main positive chronic effect of altitude training is the increase in the total volume of red blood cell mass (RCM) and haemoglobin mass and changes in respiration and blood lactate accumulation. RCM is increased in altitude residents; the critical altitude for increased RCM is around 2000 m.

When endurance athletes train at altitude the lack of oxygen stimulates the release of erythropoietin (EPO), the hormone responsible for stimulating erythrocyte production. Within the first hours in a hypoxic environment, EPO concentration increases, reaching a maximum within 24–72 h. Red blood cell production increases and haemoglobin concentration starts to increase slowly; about half of the final Hb increase is attained in 2–4 weeks. After living for 4–6 months at altitude, the final haemoglobin concentration is reached and total blood volume is increased by about 10% because plasma volume is also increased. Haemoglobin concentration is higher with higher living altitude (Fig. 5.13).

The increase in RCM is slow and a significant 2–4% increase can be observed after 2–3 weeks' altitude training. After 4 weeks of altitude training elite endurance athletes can increase their RCM by 5–6% but the individual differences in the response are great (Fig. 5.14). The iron intake before and during altitude training is essential and may be a factor that influences the individual response. Another factor could be training; increased stress of training in hypoxia, increased anaerobicity and acidity during training may depress erythropoiesis in the bone marrow, especially in the early phase of altitude training and the increase in red cell production (and RCM) is delayed or inhibited. Close to complete acclimatization to altitude takes 6–8 weeks but may compromise the improvement of some other important characteristics of elite cross country skiers (see below).

Problems of altitude training

There are some problems related to the acute and chronic effects of altitude and altitude training. Recent studies have indicated that the S_aO_2 of elite athletes is also decreased during submaximal training intensities, even at low altitudes, despite the increase in haemoglobin concentration (see Fig. 1.2). Further, heart rate during training—at submaximal workouts—is increased. From a practical point of view, the problematic aspects of training at altitude are that at a given heart rate oxygen uptake is lower, stroke volume is smaller and blood lactate concentration is higher as compared to training at sea level. Maximal cardiac output is also both acutely and chronically decreased during training at altitude, most probably because of decreased maximal heart rate (see Chapter 1). Consequently, athletes are training at lower velocity, lower heart rate and lower stroke volume when at altitude. Maximal performance, $\dot{V}O_{2max}$ and maximal cardiac output are also lower.

An increase in the activities of key enzymes involved in aerobic metabolism, myoglobin and capillary density in skeletal muscles have been observed when the absolute training intensity is the same as at sea level (see Fig. 5.22). However, the absolute training intensity is lower at altitude because athletes are obliged to train at about the same relative training intensity as at sea level and then the oxidative capacity does not change when living and training at medium altitude or living at higher altitudes. However, athletes raised and trained at altitude seem to have a higher capacity to oxidize lipids than athletes raised at sea level.

Catecholamine concentrations and anaerobic potential for energy production from glycogen increase at altitude. Muscle buffer may also be increased after training at altitude but, because blood buffer capacity is decreased at altitude and maximal blood lactate concentration tends to decrease rather than increase during prolonged exposure to altitude, maximal anaerobic capacity probably stays unchanged. The maximal anaerobic performance capacity of elite skiers during altitude training has decreased probably because of decreased training velocities at altitude and consequent impairment of neuromuscular performance characteristics.

Performance and training at altitude

During prolonged training at altitude RCM increases slowly and $\dot{V}O_{2max}$ increases concomitantly the longer the stay and training period at altitude (Fig. 5.15).

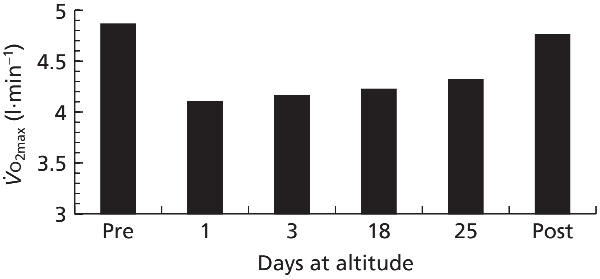

Fig. 5.15 $\dot{V}O_{2max}$ during training at an altitude of about 2200 m increases slowly towards the values attained at sea level (pre and post). (Modified from Saltin 1997.)

However, $\dot{V}O_{2max}$ at altitude does not increase to sea level values within the first 3–4 weeks of altitude training.

Acclimatization to altitude improves performance at altitude even though the changes in $\dot{V}O_{2max}$ are small. This can be seen in the gradually decreasing submaximal heart rate, lung ventilation and blood lactate during the course of altitude training. Figure 5.16 shows that the heart rate (a) and blood lactate (b) of cross country skiers are decreased during submaximal treadmill running at four different intensities. Heart rate and blood lactate of national team skiers increased at the beginning of the altitude training camp but a decrease to sea level values can be attained within 2–3 weeks of altitude training. During skiing the blood lactate–heart rate curve is initially shifted to the left, indicating the beginning of altitude training, but a positive acclimatization effect can be seen during the training camp (Fig. 5.16c). As a rough estimate, the training heart rates should probably be 5–10 b.p.m. lower at the beginning of altitude training than at sea level to avoid too much anaerobic energy production during training at altitude.

Increased catecholamines, cortisol and resting and standing heart rate values indicate increased stress during altitude training. This emphasizes the need for improved recovery at altitude. The increased stress and hypoxia also increase the use of carbohydrates as a fuel for training exercises, increasing the need for carbohydrates in meals.

Observations and measurements on national team athletes suggest that a simple orthostatic heart rate response reflects the changes in hypoxic stress and autonomic regulation, as well as the changes in

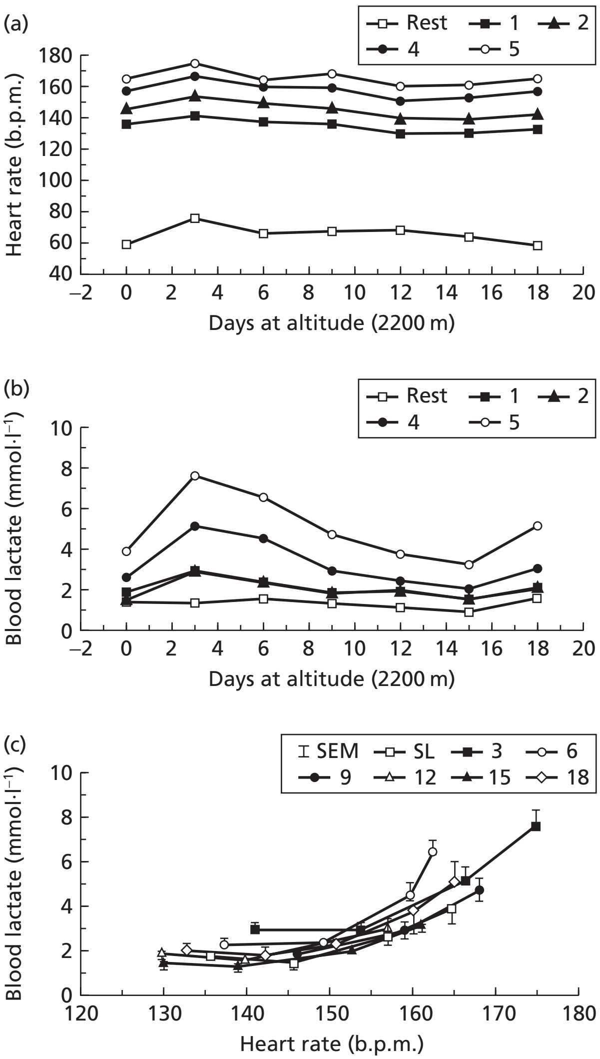

Fig. 5.16 (a) Blood lactate and (b) heart rate during 4 × 4 min incremental submaximal treadmill running at constant velocity measured every third day at altitude of 2200–2300 m in national team skiers. Treadmill inclinations were 1, 2, 4 and 5° during consecutive 4-min periods. (c) Blood lactate–heart rate curves measured during skiing on snow at different velocities. After about 10–15 days blood lactate and heart rate had decreased to pre-altitude sea level values. At the end of the training camp the values started to increase, suggesting that the training and non-training stresses exceeded the ability of the body to recover (see also Fig. 5.17)

plasma volume during altitude training and acclimatization in cross country skiers (Fig. 5.17). After standing up the heart rate increases to high values within 10–20 s and then, after a rapid decrease, finds its final standing level during and after the second minute of standing. Supine heart rate, initial 10–20 s $\mathrm{HR}_{\mathrm{peak}}$ and 2 min $\mathrm{HR}_{\mathrm{stand}}$ increase at the beginning of altitude training and start to decrease gradually after 5–10 days, indicating improved acclimatization. These supine and standing heart rate changes are similar to the changes in submaximal exercise heart rate. Figure 5.17c shows that heart rate in the ortho-static test also reflects the changes in $\dot{V}\mathrm{O}_{2\max}$ during altitude training.

Practical advice

Practical advice is difficult to give for altitude training; however, skiers should drink plenty of fluids, eat carbohydrates and take care of their iron balance before and during altitude training. Means of recovery must be enhanced. Some data indicate that caffeine improves the performance of skiers when racing at altitude. Close to full acclimatization to altitude takes 6–8 weeks but may compromise the improvement of some other important characteristics of elite cross country skiers. When acclimatizing for competitions at 600–1200 m altitude, 1–2 weeks is the minimum period necessary, whereas 4–5 weeks is needed for competitions at 1500–1800 m. In both cases, a higher altitude of 2000–2500 m is preferably used for living and training. To keep up neuromuscular performance ability, short-interval training at sea level race velocity can be used. Another option is to do some of the training exercises at lower altitude, which could also minimize the reduction of maximal cardiac output and maximal heart rate. The few days before the race should be reserved for final adaptation to the altitude of the race. Another option is to consider several shorter altitude training periods over the last 2–3 months, with a total duration of 4–6 weeks at altitude. Yet another option is to race within 24–48 h of arrival at race altitude.

Altitude training for improving sea level performance

The main positive effect of altitude training for an improved sea level performance is the increase in

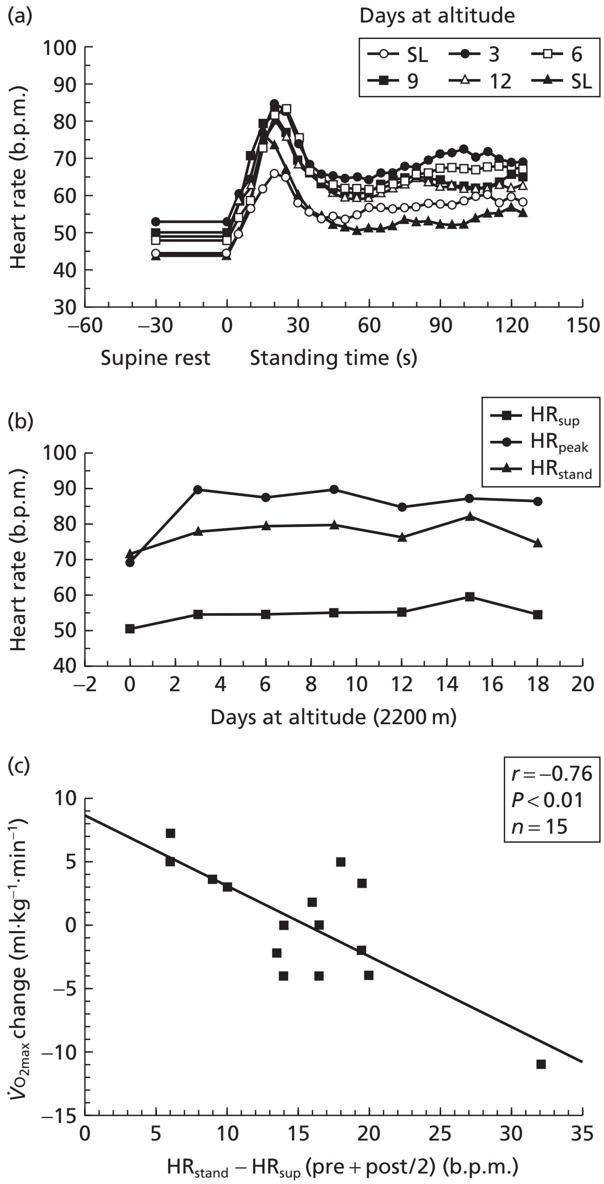

Fig. 5.17 (a) Orthostatic heart rate curves during altitude training in the same national team skiers as in Fig. 5.16. (b) Orthostatic heart rate indices increased considerably at the beginning of altitude training and thereafter adaptation occurred so that individually within 1–2 weeks pre-altitude heart rates were almost attained. (c) Relationship between orthostatic heart rate and $\dot{V}O_{2max}$ changes during altitude training. When comparing values before and after altitude training, skiers with small difference between standing and supine heart rate were able to increase their $\dot{V}O_{2max}$ during altitude training, while a large increase in heart rate was connected to a decrease in $\dot{V}O_{2max}$.

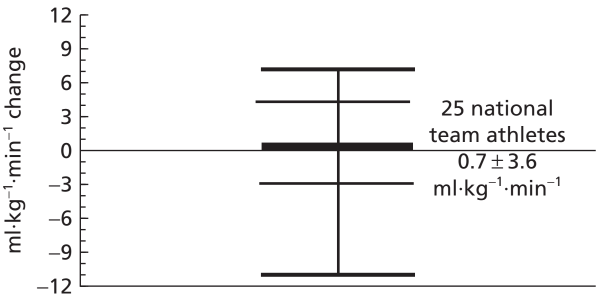

Fig. 5.18 Mean (±SD) and individual range of changes in sea level $\dot{V}O_{2max}$ of 25 elite cross country skiers who have either lived and trained at 1600–1800 m for 3 weeks, or lived at 1500 m and trained at 2300–2400 m for 2 weeks. About one-third of skiers could increase their $\dot{V}O_{2max}$, no effect was seen in one-third, while one-third had a decrease in $\dot{V}O_{2max}$ after altitude training.

RCM and haemoglobin mass (see above). The total blood volume stays elevated for 3–4 weeks after descending back to sea level. Haemoglobin concentration is increased at altitude but after descending to sea level plasma volume increases, compensating for the increase in total volume of haemoglobin mass and RCM, so that haematocrit and haemoglobin concentration return to the same level as before altitude training. The increases in plasma volume and total blood volume occur in 2–3 days. The increase in total blood volume may be as high as 0.5–1.0 l. The increased blood volume and RCM start to decline slowly at sea level and the effect of altitude training is lost in 4–6 weeks.

Because of increased total blood volume, the maximal stroke volume and maximal cardiac output may also increase and allow for an increased $\dot{V}O_{2max}$ after return to sea level. However, as described above, training at altitude in hypoxia also includes some problems which negatively influence the development of different characteristics related to sea level $\dot{V}O_{2max}$ and sea level performance. There are also very great individual differences in the responses to altitude training. Consequently, despite the increase in RCM, sea level $\dot{V}O_{2max}$ and sea level performance may not improve after training at altitude in about two-thirds of athletes. However, one-third of athletes seem to benefit from altitude training (Fig. 5.18).

Another positive effect of altitude training for improved sea level performance is an increase in buffer capacity. A relationship between improved performance and change in muscle buffer capacity has been observed in Nordic combined skiers after returning to sea level. However, anaerobic performance may not be improved in elite cross country skiers as maximal and submaximal anaerobic muscle power and performance were impaired after returning to sea level, probably because of the decreased training velocity and impaired neuromuscular determinants of performance. Subjective questionnaire evaluations of cross country skiers also suggest that force–velocity characteristics and performance capacity as a whole are decreased at sea level after altitude training.

The control of respiration is changed at altitude to correspond with the decreased $P_{\text{i}}\text{O}_2$ at altitude. After returning to sea level, a few days with at least one demanding training session at race pace must be reserved for allowing the respiration to adjust to sea level conditions before the actual race.

When using altitude training for enhancing sea level performance, the training at altitude is the key point. The velocities needed during sea level racing must be trained in one way or another. Usually, the training volume is decreased, high-velocity interval training is done and additional time is reserved for improving recovery.

Live high, train low

Recently, a new approach of 'living high' and 'training low' has been introduced. In several studies which have been carried out, the athletes lived at a medium altitude of 2500 m and trained at low altitude. 'Training low' avoids most of the problems related to altitude training; training velocities are higher than when 'training high'. The athletes have had an improved sea level $\dot{V}\text{O}_{2\text{max}}$, maximal lactate steady state, and sea level performance, indicating the low altitude training effect. This approach also gives the acclimatization effect: increased total blood volume and red cell mass (Fig. 5.19). The acclimatization effect seems therefore to be the most important factor in altitude training for improving performance capacity at sea level but not necessarily the actual training at altitude. The live high, train low approach has also improved the low altitude sea level performance of elite cross country and Nordic combined skiers when preparing for world championship races.

The most recent studies indicate that the best living altitude is around 2000–2500 m, while the training altitude should be as low as possible. When living high, training low is used to prepare for races at altitude (<1800 m) the 'low altitude training' should be done close to the altitude of the race.

Simulated altitude training

Traditionally, hypoxic chambers have been used to study the effects of acute hypoxia but these chambers are unpleasant if used to acclimatize for several weeks. Hypobaric training rooms were used in the former East Germany for training before important races at sea level or at altitude.

Simulated live high, train low

In Finland, the altitude house was developed in 1993 to create a normobaric hypoxic living atmosphere for simulating altitude and to study and utilize the live high, train low approach (Fig. 5.20). The altitude house consisted of an air compressor, nitrogen membrane generator, mixing system and two independent control systems. The nitrogen produced was mixed with the ambient air and the mixed air was conducted to the living room and bedrooms of the altitude house, which was carefully made as airtight as possible. The concentration of oxygen was kept at 15–16%, corresponding to an altitude of about 2500 m, which allowed athletes to 'live high' although staying at sea level.

Several studies have shown that living high, training low using the altitude house approach gives the acclimatization effect. The RCM of cross country skiers increased by 5–6%, similar to normal altitude training in the mountains, if the daily exposure time to hypoxia was 12–16 h and the altitude house training period was 3–4 weeks (Fig. 5.21). During the altitude house training period, plasma volume decreased and haemoglobin concentration increased similarly to normal altitude training or live high, train low in the mountains (dry air and increased ventilation). After this period, plasma volume increased again, balancing the increase in RCM and total volume of haemoglobin mass. Consequently, haematocrit and haemoglobin concentration returned to normal sea level values while total blood volume was increased.

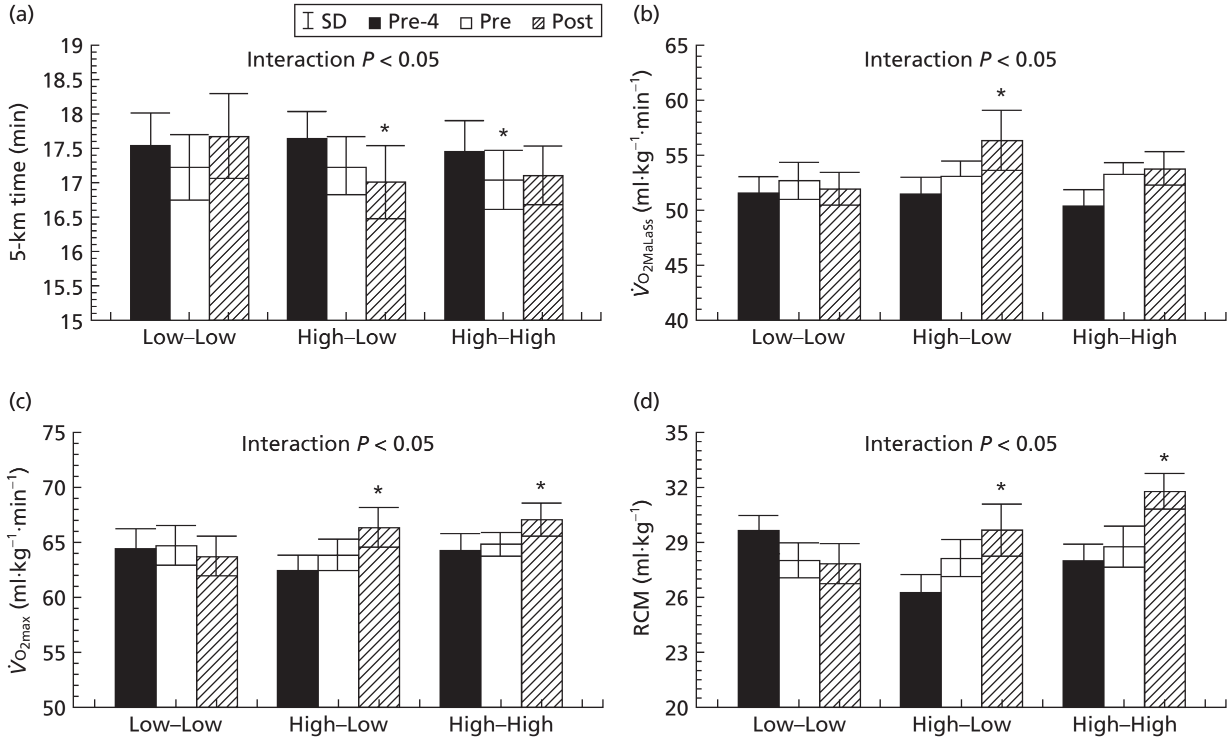

Fig. 5.19 Effect of 4 weeks' live high, train high; live high, train low; and live low, train low training period carried out after a lead-in training period at sea level (from pre-4 to pre). Live high, train low gives both the acclimatization effect (increased red cell mass, RCM, and sea level $\dot{V}O_{2max}$) and sea level training effect (improved sea level maximal lactate steady state, $\dot{V}O_2$MaLaSs, and sea level performance). Significant change from preceding measurement has been denoted by an asterisk. (Modified from Levine & Stray-Gundersen 1997.)

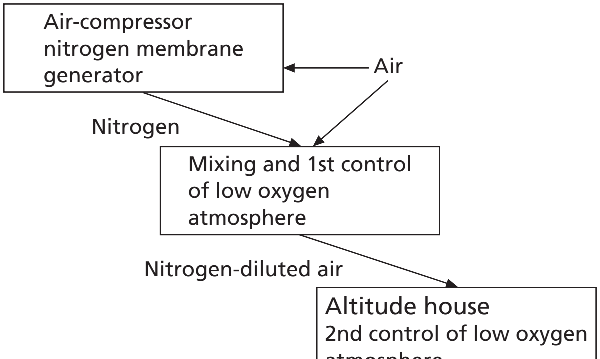

Fig. 5.20 Schematic description of the altitude house system. Nitrogen is produced by nitrogen membrane generator and mixed with the ambient air. The normobaric gas mixture with 15–16% O_2 concentration (corresponding to the altitude of about 2500 m) is forwarded to the living room and bedrooms of the altitude house.

Because the athletes trained at sea level, they also got the sea level training effect and their sea level $\dot{V}O_{2max}$ and sea level performance were improved. However, again similarly to normal altitude training, or live high, train low, the control of respiration changed during the altitude house period so that lung ventilation increased even during sea level training. An increased sea level $\dot{V}O_{2max}$ and sea level performance was not observed immediately but a few days after the altitude house training period. Therefore, after the period, one demanding training session at race pace must be reserved for allowing respiration to adjust to sea level conditions before the actual race at sea level.

The acclimatization effect and sea level training effect during and after the altitude house training period could be seen in the heart rate and blood lactate responses during submaximal exercise. During

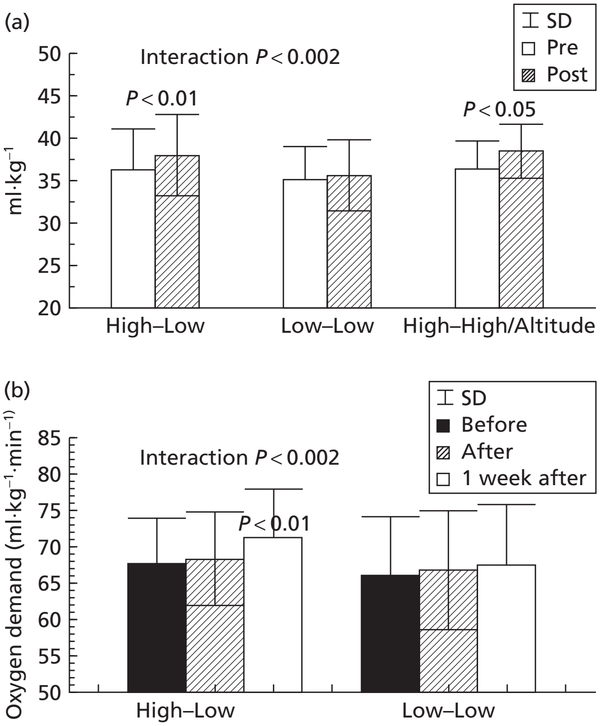

Fig. 5.21 RCM and sea level $\dot{V}O_{2max}$ of 18 cross country skiers and four triathletes (17 men, five women) after altitude house training (high–low, $n = 12$) or normal sea level training (low–low, $n = 10$) for 25 days. The increases in RCM in high–low are similar to those after normal altitude training of similar duration (high–high, 14 elite distance runners). The increase in $\dot{V}O_{2max}$ and treadmill performance is observed 1 week after the altitude house training period. (Modified from Rusko *et al.* 1999.)

the first week heart rate and blood lactate measured during submaximal exercise *in hypoxia* increased and thereafter they started to decline. After 4 weeks of altitude house training, heart rate and blood lactate concentration during submaximal exercise *in hypoxia* were the same as in normoxia before the altitude house period. During the period, heart rate and blood lactate measured during submaximal exercise *in normoxia* decreased continuously week by week and after the altitude house training period they were significantly lower than before.

Training at sea level during the altitude house period can be kept similar to normal sea level training. The only difference is that more emphasis should be put on recovery because the hypoxic living and sleeping atmosphere is not optimal for recovery.

A practical approach used by elite skiers is that they first acclimatize at sea level using altitude house training for 7–14 days. Then they travel to the training camp at altitude and, during summer ski-training camps at altitude, they can immediately keep up a high skiing velocity on the glacier. Similarly, when preparing for World Cup or other international races at low or medium altitude, a preliminary 7–14-day altitude house training period before 1–3 weeks' normal altitude training in the mountains has been used to prolong the total duration of altitude acclimatization and to guarantee as high an increase in RCM as possible without compromising the training velocities too much. Some athletes (rowers and skiers) have also successfully used additional oxygen breathing during altitude training when preparing for races at sea level. Research data on runners also support this approach.

Living high, training low can also be used for preparing for sprint ski races at sea level. A 2-week altitude house training has improved 400 m running performance and anaerobic muscle power of elite 400 m runners. Muscle buffer capacity is also improved after returning to sea level from normal altitude training camp and the performance improvement has been related to the increased muscle buffer capacity.

Finally, living high, training low can also be carried out at altitude using oxygen breathing during training. This kind of training improved the performance of athletes who had carried out altitude training for a prolonged time without improvement in performance.

Use of hypoxic training at sea level

Hypoxic training in either a hypobaric chamber or by breathing normobaric hypoxic gas mixtures (e.g. from gas tank or using special portable device) has been used for enhancing performance both at altitude and at sea level. Recent studies of living in normoxia and training in hypoxia suggest that this approach may increase muscular endurance and sea level performance, although results have been contradictory. However, the acclimatization effect is not attained by this approach. Figure 5.22 shows that if the same training intensity can be used during hypoxic training

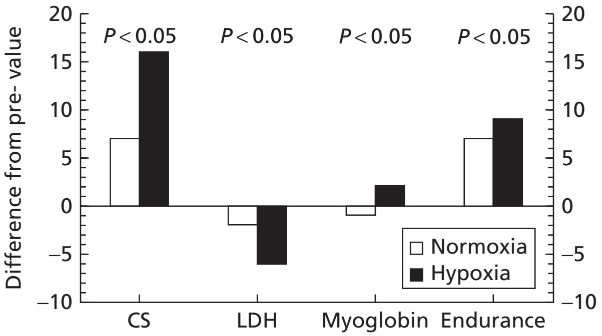

Fig. 5.22 Comparison of muscle enzyme and myoglobin changes during one-legged training for 4 weeks in hypoxia vs. normoxia. Here the training load was the same for both legs and more positive changes were seen in the leg trained in hypoxia. (From Terrados 1992.)

as during normoxic training, positive muscular changes can be attained.

Main points to remember about altitude and simulated altitude training

- Altitude training increases $\dot{V}O_{2\max}$, RCM, blood volume and performance at altitude.
- Altitude training may increase $\dot{V}O_{2\max}$ and performance at sea level but individual responses may mask the effects of altitude training.
- Individual responses seem to be related to the initial iron stores, to low training velocity at altitude and to the additional stress of hypoxia.
- Training at low altitude or at sea level and an emphasis on recovery are necessary to avoid the problems related to training at altitude and to keep up the sea level training velocities and training effects.
- Careful supervision of training at altitude including submaximal blood lactate and heart rate measurements, as well as orthostatic heart rate test, is recommended.
- Living high, training low using normal altitude or altitude house training increases RCM and allows training at sea level training pace, thus avoiding the problems related to training at altitude. A significant increase in RCM is attained if the daily exposure to hypoxia is 12–16 h and the duration at least 2–3 weeks.
- Iron status has to be checked and iron supplementation is recommended before, during and after altitude training.
- During altitude training or altitude house training drink plenty: plasma volume, training heart rate and stroke volume of heart do not change so much.
- Eat carbohydrates: enhanced stress and hypoxia increase your carbohydrate consumption.
- Caffeine may help if an intensive training session is performed at altitude.
- After returning to sea level do at least one intensive training before the race to allow the respiration to adjust to the new environment.

Nutritional advice for cross country skiers

Main principles of good nutrition

Both general nutritional information and sport-specific guidelines are readily available in numerous books. *Nutrition in Sport*, edited by R. Maughan, is a new book in the IOC Medical Commission publication series which is highly recommended for acquiring more in-depth knowledge in the field. This section, therefore, only attempts to present some basic nutritional information related to endurance sports such as cross country skiing to skiers, coaches and medical staff with limited previous knowledge in the area of nutrition. The most essential principles of nutrition for athletes may be summarized in the following.

1 Eat enough food to compensate for training-induced energy expenditure.
2 Eat high quality food rich in vitamins and minerals.
3 Eat a wide variety of foods.
4 Eat foods with a high carbohydrate content after training.
5 Eat a minimum of 3–4 meals per day, depending on training volume.

Eat enough food

In an endurance sport such as cross country skiing where large groups of muscles are used often for several hours each day, it is imperative to resupply the body with adequate amounts of calories to balance the large energy expenditure during training. Energy turnovers as large as 20 $MJ \cdot day^{-1}$ (megajouls per day) in women and 35 $MJ \cdot day^{-1}$ in men were measured in Swedish national team cross country skiers during an altitude training camp. Some of the skiers had serious problems consuming enough food to compensate for these huge energy expenditures. However, over a 1-week period, which included 1 day of reduced training, the athletes were able to eat enough to reach a caloric balance. Therefore, it is important to be aware of the caloric deficit that may develop during intensive training periods and also to try to eat well on days with less or no training.

Body weight measurements are not a sensitive method for monitoring short-term changes in caloric balance, because they do not discriminate between changes in food/caloric intake and liquid/non-caloric intake. In other words, if you burn 1 kg of fat and carbohydrates and replace it with 1 litre of water, your pre-exercise body weight is regained, but you have a caloric deficit that will reduce the efficiency of reloading your energy stores for the next days' training sessions. However, if measured in the morning over a longer period of time, body weight may be indicative of the overall balance between total energy expenditure and intake.

The volume of food that an athlete needs to consume to keep a caloric balance during periods with large training loads may present a problem because it requires athletes to eat more than they want. During these periods, increasing the fat content of the food could reduce this problem because the number of calories stored in 100 g of fat is almost four times as many as in 100 g of carbohydrate.

Eat high quality foods

In addition to adequate caloric supply, the body also needs high quality food and not just 'empty' calories from plain fats or sugars. In simple terms, it is vital to be concerned with both quantity and quality of food intake. A variety of proteins, fats and carbohydrates from various food sources are necessary to build the many tissues of the body, and supply the body with the best energy for physical performance. The term 'high quality foods' is not easily defined, but includes some of the characteristics listed below.

- Foods that are *fresh*—such as vegetables, fruits and berries.
- Foods that contain a *variety of nutrients*—such as wholemeal bread, fish and white meat.
- Foods that are *not manipulated*—as is meat from hormone-treated animals.
- Foods that are not *overly processed* or overcooked before eaten—e.g.TV dinners.
- Foods that are grown in rich soil and *not contaminated* with chemicals or pollution.

In addition to the concerns regarding the quality of macronutrients in the food (fats, proteins and carbohydrates), the micronutrient content (vitamins, minerals and trace elements) is also very important to optimal health and sports performance. Potato chips and chocolate may be good sources for plain calories, but they supply very few vitamins, minerals and trace elements. These micronutrients are needed to keep vital metabolic processes going in the immune system, the muscles or any other functional unit of the body.

The amount of vitamins, minerals and trace elements that we get through various foods are not only dependent on the *quality* of each original food product (e.g. a tomato or fish fillet), but also on the way the food source is *processed* into a particular product (e.g. a pizza or fish soup) and treated before eaten. In very general terms, the more the food is processed and cooked before appearing on the plate, the fewer vitamins, minerals and trace elements will be preserved. In order to attain an optimal content of both macro- and micronutrients in their food, athletes need to be conscious about what type of food to select and how to prepare it. This is particularly important for athletes who need to replace large amounts of nutrients every day. The pre-made 'TV-dinner' or 'fast food' from the freezer might not give the competitive edge in a major ski championship!

The recommended daily allowance (RDA levels) of various vitamins, minerals and trace elements can differ between countries. Moreover, these RDA levels are based on the minimum intake of each substance that should prevent malnutrition and illnesses in the general population. Athletes with substantial energy expenditure may be in need of larger quantities of vitamins, minerals and trace elements than the national RDA levels. However, an increased micronutrient intake is normally secured through larger amounts of high quality food products among endurance athletes (Fig. 5.23).

Eat a wide variety of foods

In order to secure sufficient intake of micronutrients, athletes also have to be concerned with the *variety* of food in their daily diet. Vitamins, minerals and trace elements are found in large concentrations in some food sources, but in minimal quantities in others. Some of these substances are bound to water molecules in the food while others are bound to fat molecules. Therefore, a good combination of all major

Fig. 5.23 There is a close connection between good nutritional habits and performance in endurance sports. A sufficient caloric intake and a wide selection of food sources form the basis for optimal recovery from training and preparation for cross country races.

food sources such as dairy products, bread, cereals, fruits, vegetables, rice, pasta, potatoes, meat, fish and other seafood should be included. Because many of the micronutrients are not produced by the body itself, the availability of these substances for metabolic purposes relies on a steady and balanced intake through the diet.

Selecting a wide variety of foods is not only important for the micronutrient intake but also critical in order to achieve a good balance of the macronutrient intake (carbohydrates, proteins and fats). There are a great number of different carbohydrates, proteins and fats in the various food products. The body needs many of these individual substances either prefabricated or in the original form and, because the body cannot synthesize them itself, the dietary intake is paramount.

Regarding the overall distribution of carbohydrates, proteins and fats in the diet of an athlete, sports nutritionists recommend that 60–65% of the daily energy intake comes from carbohydrates, 12–15% from proteins and 25–30% from fats. Only a 5–7-day meticulous recording of all food and liquid intake can ultimately determine if the athlete's diet complies with this guideline. However, it has consistently been found that if a careful selection and combination of the basic food products mentioned above is used and a well-balanced dinner is included every day, the recommended percentages of carbohydrates, fats and proteins will be achieved. Nevertheless, it may be a good strategy to have the nutritional habits of all new skiers on a team evaluated by a sports/clinical nutritionist. Then, if the initial screening reveals nutritional concerns, a dietary record should be completed and proper nutritional interventions made as soon as possible.

Eat foods with high carbohydrate content

The intake of carbohydrates recommended for athletes is somewhat higher than the national guidelines for the normal population, because carbohydrates are very important fuel sources during exercise of moderate to high intensity. Perhaps more importantly, the carbohydrate stores (glycogen in both liver and muscles) may be emptied after only 2 h of strenuous exercise. Fat is also an important fuel, particularly during low to moderate intensity exercise, but fat stores last much longer than carbohydrate stores. In order to reload the glycogen stores after strenuous exercise, it is of vital importance to eat enough carbohydrate-rich food. However, athletes should know that there are different types of carbohydrates, from simple sugars such as glucose and fructose to complex sugars such as starch. A sufficient mixture of the various carbohydrates is vital to athletic performance, with an emphasis on simple sugars (sources 1–4) during and immediately following exercise, while the more complex sugars (sources 5 and 6) should be consumed during meals. Simple sugars are rapidly absorbed from the gut into the blood circulation (they have a high glycemic index) and are thus readily available as energy for the working muscles. Conversely, foods with complex sugars have a slower rate of absorption from the gut and are thus less effective as an instant energy source (they have a low glycemic index). However, the energy in the complex sugar molecules is densely packed and within a few hours after a post-exercise meal will result in effective restoration of glycogen stores both in muscle and liver.

Some common sources for carbohydrates

1 Sports drinks and lemonade.
2 Chocolate and ice-cream.
3 Sweet cookies, rolls, muffins and biscuits.
4 Fruits and fruit juices, grapes/raisins and berries.
5 Cereals and bread.
6 Pasta, rice and potatoes.

Having underlined the special concern for plenty of carbohydrates in the athlete's diet, it must not be forgotten that proteins are also important nutrients for a cross country skier who imposes prolonged metabolic stress on large masses of muscles. Milk, cheese, eggs, meat, fish, pies and beans are good sources of dietary proteins. In fact, there is some indication of increased effectiveness in restoring glycogen in muscle after prolonged exercise if proteins are consumed in addition to carbohydrates during the first hours post-exercise.

Eat a minimum of four meals per day

There is no ideal number of meals per day for an athlete, but meals should not be separated by more than 4–5 h during the day. The total energy intake could be divided into a minimum of three meals per day, with a couple of snacks before and after practices or five meals with no extra snacks. A 'middle of the road' alternative may be recommended with four regular meals, each separated by about 4 h, and one snack (ham and cheese sandwich, energy bar or fruit) immediately after a training session. If the athlete has two training sessions per day, effective reloading of muscle glycogen between the two sessions is imperative. An extra snack, preferably immediately after the first session, should therefore be included in addition to a regular lunch or afternoon meal.

Nutritional supplements

The use of nutritional supplements has increased extensively over the last two decades in most sports. A recent study showed that 95% of the Norwegian national cross country and Nordic combined ski teams used one or more dietary supplement per day, even if all carbohydrate supplements were excluded. This was observed in spite of the fact that 94% of skiers reported adequate nutritional habits. The reasons for taking extra vitamins, minerals, trace elements and dietary fatty acids vary considerably. It may be based on medical indications; e.g. as part of diagnosing low iron stores or calcium deficiency in a young female skier. However, in most instances the supplementation takes place for a number of non-medical reasons ranging from improved general health and recovery after training sessions to unsubstantiated claims of enhanced performance (Fig. 5.24).

Fig. 5.24 When training and competing at moderate or high altitude, cross country skiers should check their nutritional status and particularly their iron stores (ferritin levels). Supplementation with certain vitamins and minerals should be evaluated on the basis of actual intake and estimated turnover of all micronutrients. Supplementing high doses of certain vitamins and minerals may be harmful and should be avoided.

It is impossible to establish a 'consensus statement' regarding if, when and what nutritional supplements should be used for an endurance athlete. From a scientific and medical point of view, if good nutritional habits are followed and no deficiencies are disclosed, there should be no need for dietary supplements. Nevertheless, there may be situations where supplements must be considered, particularly if nutritional interventions are hard to make.

Nutritional supplements may be considered in the following situations

1. Periods of low caloric intake (illness, limited food access, etc.)
2. Periods of weight reduction.
3. Periods with limited variety of food selection.
4. A diet without essential foods such as fish, dairy products, grains, etc.
5. Change to a vegetarian or vegan diet.
6. Periods of heavy menstrual bleeding.
7. Periods of intensive training, particularly at high altitude.
8. Periods with frequent respiratory infections.

There is some scientific support for a general recommendation of vitamin C supplementation to athletes, particularly during periods of intensive training and competitions or altitude training. However, the amount of vitamin C (400–800 mg·day^{-1}) could very well be supplied by additional fruits and juice within the normal diet. Although there is evidence of free radical involvement in exercise-induced muscle injury, supplementation with antioxidants such as vitamin E do not appear to prevent muscle damage caused by exercise unless a vitamin E *deficiency* is evident. As it is still unclear whether exercise induces lipid peroxidation in the human body, the beneficial effect of vitamin E supplementation has not yet been fully established. Nevertheless, some scientists advocate a moderate dose of 100–200 mg vitamin E·day^{-1} for endurance athletes during periods of intensive training and competitions or altitude training to reduce possible exercise-induced oxidative damage. Sufficient iron intake is also a special concern for young female athletes and for most skiers using altitude training. If iron stores are low before going to altitude camps, the expected increase in red blood cells and aerobic capacity may be eliminated. Therefore, ferritin values should be checked in sufficient time to correct potential iron deficiencies (ferritin <30 mmol·l^{-1} in men and <25 mmol·l^{-1} in women) before training at altitude above 1800 m.

A general warning on the use of nutritional supplements should be issued both for the purpose of not overdosing on any of the micronutrients and because of potential conflicts with banned substances. Supplementing high doses of one mineral may inhibit necessary uptake of another in the gut and thus cause a deficiency. Another concern is the possibility of reaching toxic levels of a micronutrient, as could be the case in excessive use of iron supplements. Furthermore, any commercially produced supplement carries a risk of being mixed or contaminated with banned substances on the IOC list. Even though this risk may be minimal for regular vitamin and mineral supplements produced under good manufacturing standards, it can never be eliminated. A particular warning should be added towards supplements marketed with strong but often unsubstantiated claims of improved health, body composition and/or performance. These products may deliberately be mixed with banned substances such as anabolic steroids or ephedrine, which are known to have performance enhancing effects, without being identified on the product label (for further discussion on the effect of nutritional supplementation on exercise-induced immunosuppression see Chapter 4).

Main points to remember about nutritional advice for skiers

- The main principles of good sports nutrition for endurance athletes are:
  1. eat enough food over 3–5 meals·day^{-1} to compensate for energy expenditure in training;
  2. eat a wide selection of high quality food rich in vitamins and minerals; and
  3. eat foods with a high carbohydrate content after each training session.
- Energy expenditure from performing two training sessions per day may exceed the athlete's ability to eat enough calories in their daily diets. Increasing the fat content of the diet temporarily can reduce the risk of caloric deficits during intensive training periods.
- A variety of proteins, fats and carbohydrates from various high quality food sources is necessary to rebuild the many tissues of the body, and provide the best energy for physical performance.
- It is recommend that endurance athletes should obtain 60–65% of their daily energy intake from carbohydrates, 12–15% from proteins and 25–30% from fats.
- Daily intake of a balanced diet with major food sources such as dairy products, bread, cereals, fruits, vegetables, rice, pasta, potatoes, meat, fish and other seafood will normally secure a sufficient intake of most micronutrients.

- In order to reload the glycogen stores after strenuous exercise, it is importance to eat enough foods that are rich in various carbohydrates with an emphasis on simple sugars (sources 1–4) during and immediately following exercise, while the more complex sugars (sources 5 and 6) should be consumed during meals.
- Increased effectiveness in restoring muscle glycogen stores after prolonged exercise may be achieved if protein-rich foods such as milk, cheese, eggs, meat, fish, pies and beans are consumed in addition to carbohydrates during the first hours of recovery.
- Nutritional supplements should be considered during periods of:
  1 low caloric intake;
  2 planned weight reduction;
  3 little variety in the diet;
  4 lack of essential food sources;
  5 change to vegetarian or vegan diet;
  6 heavy menstrual bleeding;
  7 frequent respiratory infections; or
  8 large volumes of training, particularly at high altitude.
- A general warning on the use of nutritional supplements should be issued, both for the purpose of not overdosing on any of the micronutrients and because of potential conflicts with banned substances.

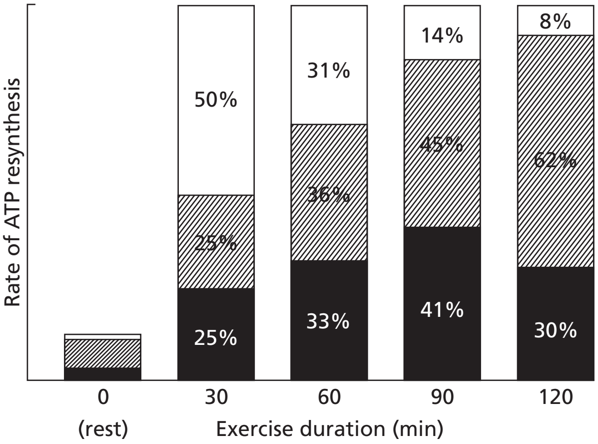

Fig. 5.25 Changes in energy sources during prolonged strenuous exercise Black, blood glucose; hatched, plasma free fatty acids; white, muscle glycogen. (From Maughan R.J. (ed) *Nutrition in Sport.*)

Carbohydrate loading and fluid replacement

Energy sources in exercise

Carbohydrates and fats are both important fuels for working muscles. However, they contribute differently to the total energy turnover during exercise, depending on intensity and duration of the exercise. Despite the fact that the body has much more energy stored as fat compared to glycogen (approximately 390,000 kJ as fat vs. 7500 kJ as carbohydrates in a 70-kg man), there is a definite limit to how much fat fuels can contribute to increased work output during high intensity exercise.

Fat fuels—mainly in the form of free fatty acids—are the major energy sources for low intensity exercise (25–50% of $\dot{V}O_{2max}$). As the work intensity is increased, a proportionally greater amount of carbohydrate (primarily stored as glycogen) compared to fat will be used in the working muscle. At intensities above 50–60% of $\dot{V}O_{2max}$, carbohydrates take over as the primary energy source. If the work intensity is increased even further, almost all the energy has to come from carbohydrates (see also Chapter 1). This is supplied from glycogen stores in muscle and liver, or from glucose molecules in the blood supplied by carbohydrate drinks (or foods) consumed while exercising. The relative contribution of the major fuel sources for energy (ATP) production is shown in Fig. 5.25. As there is a limit to how much glycogen can be stored in the body before exercise, a shortage of this fuel will develop after a certain duration of exercise. At moderate intensities (40–60% of $\dot{V}O_{2max}$) glycogen stores may last for 3–4 h, but at higher intensities (70–90% of $\dot{V}O_{2max}$) the stores may be depleted in 90–100 min (see Fig. 5.26). Not surprisingly, this progressive limitation of carbohydrate availability within the working muscle will lead to a decrease in performance, even before the fuel is totally depleted. When glycogen stores are completely empty, a drastic decline in performance is seen. This is a situation that all endurance athletes want to avoid.

Theoretically, there are three potential strategies to limit the problem of fuel shortage during prolonged strenuous exercise:

1 increase the capability of storing glycogen in muscle before exercise/race;

2 increase the supply of carbohydrate to the working muscles during exercise/race; and

3 increase the fat utilization during exercise.

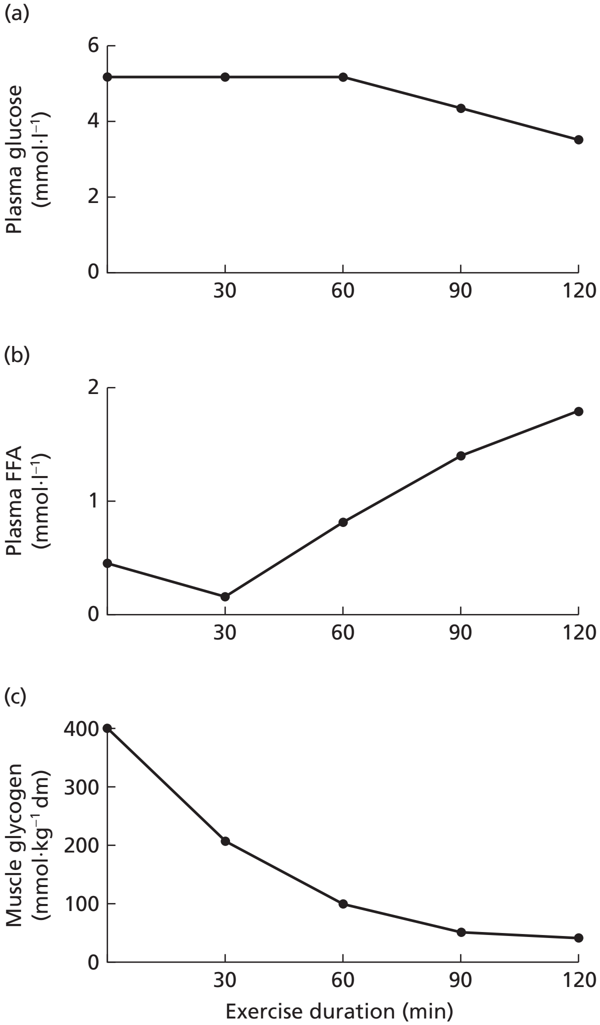

Fig. 5.26 Muscle glycogen, blood glucose and free fatty acid changes during prolonged exercise.

Carbohydrate loading

The first strategy has been called 'glycogen supercompensation'. Several scientific studies have shown increased levels of glycogen in muscles after two different regimes of dietary intake and exercise protocols over several days. In the classical regime, the athletes completed an exhaustive bout of exercise 9 days prior to a race to deplete their glycogen stores and thereafter consumed a high protein and high fat diet on the following 3 days. A new exhaustive bout of exercise was completed on day 5 prior to the race, but then followed by 3 days on a high carbohydrate diet. On the day of the race, a 100% increase above the initial muscle glycogen concentration was demonstrated with this regime. In another less complicated regime, the athletes ran at 75% of $\dot{V}O_{2max}$ for 90, 40, 40, 20 and 20 min over a 6-day period and then rested on the last day. When consuming a diet with 50% carbohydrate on the first 3 days, followed by a diet with 75% carbohydrate on the last 3 days, these athletes also increased their glycogen stores approximately 100% above initial level. In conclusion, both the classical and the modified regimes seem to be effective in elevating glycogen stores to 'supranormal' levels, but the modified regime—which does not include two exhaustive exercise sessions—has easier diet routines and lasts only 6 days.

Carbohydrate turnover

Even though the phenomenon of glycogen supercompensation has been demonstrated, recent studies have not been able to reproduce the same glycogen supercompensation effect. There are also very limited scientific data suggesting that supercompensation will result in enhanced performance in a race. However, plenty of research has demonstrated that intake of carbohydrates during prolonged strenuous exercise has a performance enhancing effect.

The efficacy of fuel utilization (oxidation of fat and carbohydrate) in the muscles determines the amount of energy that can be produced per minute. The speed by which fat and carbohydrate can be utilized in the tissue is called the oxidation rate. There is a limit to how fast the fuel can be used in each muscle cell and subsequently how fast energy can be created. This upper limit is called 'maximum rate of oxidation' and for carbohydrates the maximal level is about 1.0–1.3 g·min^{-1}. This means that the muscles cannot burn more than 1 g of carbohydrates in 1 min, and therefore not create additional energy, even though the muscles were supplied more than 1.3 g carbohydrate·min^{-1}. As long as this amount of carbohydrates can be provided from glycogen stores in the muscle itself or from the liver, the maximum oxidation rate is achieved and generation of energy from the muscles is sustained. However, when glycogen stores are limited or emptied during prolonged strenuous exercise, an exogenous supply of carbohydrates becomes increasingly important to support a maximum oxidation rate and energy output in the muscles. After about 90–100 min at race speed, carbohydrates from drinks and food turn out to be the main source of carbohydrate supply. Consequently, ingesting carbohydrates during the latter part of a long distance race or exercise is imperative to uphold a high workload, but the rate of absorption from the gut seems to be a 'bottleneck' in providing the muscles with enough carbohydrate fuels. Several factors may account for the limitation of carbohydrate uptake from the gut to the blood and it seems that ingesting carbohydrates at a rate of 60–80 $g \cdot h^{-1}$ (1.0–1.2 $l \cdot h^{-1}$ of 6% carbohydrate solution) is the upper limit of what can be absorbed from the gut. Exercise training may increase the muscle's ability to use more fat relative to carbohydrates at a certain power output or percentage of $\dot{V}O_{2max}$, but the maximum rate of oxidation is fairly constant and not subject to improvement by exercise training.

Based on these scientific facts, it is quite obvious that supplying the muscles with carbohydrate fuels both before and during strenuous exercise is vital to keep a constant high speed in any endurance sport. It also explains why supplying more carbohydrate energy than the muscles can burn at maximum rate of oxidation will not result in a higher power output and therefore not improve physical performance.

Practical advice

In preparation for a long distance race, the last meal should be completed at least 3 h before the start of the race. Foods rich in carbohydrates—such as bread, oatmeal porridge or cereals for breakfast and rice, pasta or potatoes for lunch—is recommended. However, some easily digestible fat and protein sources—like cheese, omelette, ham, salami or white meat—are also needed. It is important to be able to supply adequate amounts of high quality foods without causing disturbances to the gastrointestinal tract. A precompetition meal should therefore be tested out on a strenuous bout of exercise prior to a race.

Intake of carbohydrate drinks and foods during the last 3 h before the start of a race was previously discouraged because it could increase the level of insulin and cause a subsequent decrease in blood glucose concentrations. However, unless larger meals or volumes of sweet drinks are consumed during the hours immediately before the race, the alterations in blood sugar levels are minimal and do not present a problem to the athlete. If preparing for a race of more than 80–90 min duration, small portions of carbohydrates should be consumed every 15–30 min during the last 3 h before the race. A sandwich and a banana, a muffin or a cookie may serve this purpose, but during the last hour before the start, carbohydrate–electrolyte drinks are preferable. Immediately before the ski-race, 200–400 ml of 6–8% carbohydrate solution may be consumed without any detrimental effect on insulin and blood glucose concentrations. However, gastrointestinal tolerance and instant need for urination must be controlled. Therefore, this strategy needs to be tested out in a prior training session before applied in a race setting. To achieve optimal availability of the carbohydrates to the muscle, a combination of two or more types of carbohydrates (glucose, sucrose and maltodextrins) in a drink may be advantageous. Furthermore, a near isotonic solution of the carbohydrates along with the addition of some salts/electrolytes will improve the gastrointestinal absorption and thus the availability of the carbohydrates during exercise.

During a long distance ski-race, ingesting 50–80 g carbohydrate$\cdot h^{-1}$ (approximately 800–1200 ml of 6–7% carbohydrate solution), should result in sufficient intake of carbohydrates to maintain adequate glucose supply for working muscles. However, if skiing at high intensities, the carbohydrate intake during the race can never fully compensate for the steady decline in the body's glycogen stores and cannot avoid energy shortage after about 2 h (Fig. 5.26). Carbohydrate intake—particularly during the early part of a race—will reduce the utilization of both fat and glycogen from the muscles, thereby saving some of these energy sources for later stages. A steady intake of 150–200 ml of 6–8% carbohydrate–electrolyte solution every 10–15 min from the first hour of a race is recommended (Fig. 5.27).

Fluid loss during endurance exercise

Having emphasized the need for carbohydrate fuel before and during endurance exercise, it must not be forgotten that *fluid* intake is as important as energy intake for optimal performance. Fluid loss is dependent on both exercise intensity and modality, plus a number of environmental factors such as ambient

Fig. 5.27 Fluid replacement during long-distance cross country skiing is of paramount importance for optimal performance throughout the race.

temperature, air humidity, wind, direct radiation from the sun, clothing, etc. Intense exercise on warm days, even during winter, may result in fluid loss of more than 1000 $\text{ml}\cdot\text{h}^{-1}$. Fluid loss resulting in more than 1.5–2% loss of body weight will affect performance. For a 75-kg person that is equivalent to 1200–1500 ml, and in a race fluid loss may have negative impact on performance after only 50–60 min. The main reason for this decrement in performance is that dehydration of this magnitude may lead to a reduction in blood volume with subsequently reduced stroke volume and maximal cardiac output. The result is decreased blood flow through the working muscles, which ultimately reduces oxygen supply and metabolite clearance.

In many situations during long distance cross country skiing, fluid loss may be a more serious concern than energy deficits. However, fluid intake of more than 700–800 $\text{ml}\cdot\text{h}^{-1}$ during a ski-race may present practical problems for the skiers and interfere with their performance. In preparations for such events it is important to practise drinking sufficient volumes of fluid during training to make the gastroin-testinal system tolerate fluid intake during strenuous exercise. Strategic planning of the location for 'drinking stations' on the race course is important in long-distance ski racing. A period of 10–15 s—gliding from the top of a hill—may be sufficient time to consume 150–200 ml.

In ski-races, carbohydrate and fluid replacement has normally been practised only in the 30 km race for women and the 50 km race for men. Depending somewhat on the terrain of the racetracks, most teams will serve 150–200 ml every 4–5 km, which means every 10–15 min at race speed. An estimate of the actual intake during a race was performed in the Holmenkollen 50 km classical World Cup race. The 10 best Norwegian skiers consumed a total of 1200–1600 ml during the 130–140 min race, but this was only 60–70% of the total volume served. This high waste percentage is probably not uncommon. Even though liquid consumption was not measured during this race, the fluid intake must have been far from matching fluid loss during this 50 km race, which may have been 2200–2600 ml. Thus, moderate dehydration towards the end of the race was evident, despite good efforts to avoid this during the race. Traditionally, fluid replacement has not been practised during the 30 km race for men—with a normal race time between 65 and 80 min—because major energy and fluid shortage has not been expected. Even though this may be true in most races, there have been competitions on warm days with considerable dehydration at the end of an 80-min race. Because moderate dehydration has also been shown to affect performance, it might be wise to consider serving fluid in shorter races on relatively warm days.

Fluid replacement and sports drinks

Concerning the issue of optimal *post* exercise/race fluid replacement, this is only briefly discussed here, and the reader is encouraged to consult the recommended reading for more detailed information. Nevertheless, it should be emphasized that good routines on fluid replacement are perhaps the most important measure of recovery for an endurance athlete. The primary goal should be to *prevent* exercise-induced dehydration by starting each training session in a state of liquid balance and by replacing fluid loss as soon as possible, i.e. while exercising. By doing this, the dehydration stress will be significantly reduced and the postexercise rehydration process will go faster.

When it comes to what types of fluid are most effective, it has consistently been demonstrated that the carbohydrate–electrolyte solutions are superior to plain water if the fluid loss has been of any significance (more than about 1000 ml). This is mainly because of their primacy in rapid absorption from the gut (correct osmolarity and salt content) and their ability to maintain a stable blood glucose level (carbohydrate content). Because significant amounts of salt are lost in sweat during prolonged exercise, the salt (electrolyte) content of the drink becomes gradually more important as the degree of dehydration increases. In fact, increasing the salt content of the drink consumed both during and after exercise will bring the athlete in fluid balance significantly faster than when drinking plain water only. Because the normal body fluid is 'salt water' and not 'fresh water', it is obvious that both salt and fluid replacement are important. However, salt is not very palatable in drinks and this places a limitation to how much salt can be replaced through fluid intake. That is why a little extra table salt (sodium) on food consumed after prolonged strenuous exercise may be recommended, unless hypertension or kidney problems are evident.

Several commercial products of carbohydrate–electrolyte solutions in the form of various sports drinks are available. Some may have a little more or less of the major components; some may have vitamins and minerals or so-called ergogenic components mixed in. Perhaps the most striking difference is the taste and palatability of the drinks. However, when it comes to their ability to replenish liquid, salt and energy, there is not much difference between the products (Fig. 5.28). In a survey of the scientific testing that has been carried out, it is concluded that no commercially available sports drink is significantly better than any other on these three major effects. The most important factor may be the palatability and gastrointestinal tolerability to the product, making it agreeable for plentiful consumption by the athlete.

Fig. 5.28 When replenishing fluid loss from strenuous exercise with commercial sports drinks, the selection of type or brand of these drinks is not of vital importance. However, taste and gastrointestinal tolerance may be key factors in using a drink that the athlete will consume sufficient amounts of for effective rehydration.

Main points to remember about carbohydrate loading and fluid replacement

- When work intensity is maintained above 55–60% of $\dot{V}O_{2max}$, carbohydrate—in the form of stored muscle glycogen and blood glucose—is the primary energy source for working muscle. The higher the work intensity the more carbohydrate—relative to fat—is burned.
- There is a limit to how much glycogen can be stored in the body before exercise and a shortage of carbohydrate fuels will develop after about 90 min of high-intensity exercise.
- Even though different regimes of pre-race meal and exercise have resulted in increased glycogen stores in muscles, there are very limited scientific data suggesting that this glycogen supercompensation will result in enhanced race performance.
- In preparations for a long distance race, the last meal should be completed at least 3 h before the start of the race. Foods rich in carbohydrates—such as bread, oatmeal porridge or cereals for breakfast and rice, pasta or potatoes for lunch—are recommended.

- Small portions of carbohydrates—such as a sandwich, banana, muffin or a cookie—should be consumed every 15–30 min during the last 3 h before the race, but carbohydrate–electrolyte drinks are preferable during the last hour before start.
- Research has demonstrated that intake of a carbohydrate –electrolyte solution—including glucose, sucrose, maltodextrins and sodium—has a performance enhancing effect during prolonged (>60 min) strenuous exercise.
- A carbohydrate intake of 1.0–1.5 g·min^{-1} (800–1200 ml of 6% carbohydrate solution) will provide working muscle with enough energy to maintain a maximum oxidation rate of about 1.0 g·min^{-1}.
- A near isotonic solution of a carbohydrate–electrolyte solution will improve the gastrointestinal absorption and thus the availability of the carbohydrates during exercise.
- Fluid intake is as important as energy intake for optimal endurance performance when, depending on the intensity of exercise and environmental conditions, fluid loss may exceed 1000 ml·h^{-1}.
- The primary goal of fluid intake should be to prevent exercise-induced dehydration by starting each training session in liquid balance and by replacing fluid loss as soon as possible, i.e. while exercising.
- As significant amounts of salt are lost in sweat during prolonged exercise, the salt content of the drink becomes gradually more important as the degree of dehydration increases.
- The ability to replenishing liquid, salt and energy do not differ significantly between the commercially available sports drinks. The most important factor may be the palatability and gastrointestinal tolerability of the different products in making them agreeable for plentiful consumption by the athlete.

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Chapter 6

Psychological factors in cross country skiing

Cross country skiing, especially at the elite Olympic level, is an extremely demanding sport, both physically and psychologically, and so the role of psychological factors in the preparation for optimal performance in skiing is well documented (see recommended reading). From the perspective of performance optimization, there are at least four main groups of factors that can either enhance or impair skiing performance. These include:

1. group dynamics or social psychological factors;
2. athletes' personality traits;
3. self-regulation and coping skills; and
4. situational performance-related states in practices and races.

This framework provides a multilevel focus to examine systematically the role of psychological factors in skiing performance by generating a wide range of practical questions. For instance, what are the optimal coach–athlete relationships? How is it possible to improve working relationships between athletes and service personnel and enhance the team's morale? What are the role of parents and parent-coaches in skiers' personal and professional development? What personality qualities are especially important in developing a world-class skier? How and why do some emotions enhance while others impair skiing performance in practices and races?

Based on systematic practical work with elite athletes and coaches, it seems that successful skiers need to learn four basic lessons.

1. They must know the difference between high and low quality training.
2. They should learn how to compete successfully in races under different conditions (weather, track profile, opponents).
3. They have to learn how to perform up to their potential and succeed at the right time and in the right place.
4. They should learn how to stay at the world-class level by coping with the pressures of success and performance slumps.

Failure to learn and incorporate any of these four aspects and skills early into one's performance repertoire might slow down or even prevent a skier's progress across his or her sports career.

This chapter examines some of these questions based on available research evidence and practical experience of working with Olympic-level cross country skiers. Therefore, the main emphasis is on the application of sport psychology to the solution of concrete practical problems encountered by Olympic-level skiers. The chapter starts with high quality training practices followed by preparation for ski-races and by more general problems of application of group dynamics factors and the problems of stress and burn-out in ski coaches. In conclusion, future directions and implications for coaches and athletes are discussed.

High quality practices in cross country skiing

Psychological factors in developing endurance

Cross country skiing, like several other endurance sports, involves a high amount and intensity of physical exercise aimed at developing the athletes' basic physical qualities necessary for their successful performance. However, it is important to realize that in physical training an athlete manifests different psychological qualities that can either enhance or impair the training effect of physical exercise. For instance, endurance level can be developed only by exercising until fatigue and even exhaustion and by coping with the extreme feelings of tiredness and pain. Therefore a skier has to be aware of the specific symptoms indicative of optimal (or adaptive) and maladaptive fatigue and be able to interpret them as markers of positive or negative training effects. Moreover, such experience-based awareness, acceptance and action-orientated mind-set are the components of a skier's positive attitude towards fatigue and even physical pain. The positive attitude creates a new and special meaning (significance) of physical exercise and thus helps to delay and cope effectively with fatigue. Such a positive (self-empowering) attitude to fatigue ('Fatigue is useful for me', 'I can cope with fatigue') results in a new quality of physical exercise which has also a facilitating effect on the development of such psychological qualities as individual tolerance to physical stress, persistence, goal-orientedness, etc. On the other hand, a negative attitude towards fatigue, anticipation and avoidance of pain could be a strong psychological barrier to the development of an athlete's endurance and other physical and psychological qualities. Athletes with a negative (self-defeating) attitude ('I can't stand it any longer') usually get tired quicker as they are more fatigue-sensitive and may have problems in coping with fatigue. Therefore, physical and psychological factors and qualities seem to be related bidirectionally: psychological factors affect the development of physical qualities and physical qualities affect the development of psychological qualities.

It is important to realize that fatigue is generated not only because an athlete gets tired (because of the amount and intensity of training regimens) but also because of the monotony of the repeated cyclic exercise. To delay and cope with fatigue, an athlete should have a clear idea about the training intensities and the means to achieve the training effects and optimal action-orientated mind-set regarding the tasks at hand. Specifically, the development of endurance is greatly facilitated if a skier has a categorical (unconditional) mind-set about the execution of a particular segment of the training programme or race ('It's life or death to me'). Research findings indicate that the probability of successful task completion decreases by 70% if a categorical (unconditional) mind-set is changed to a conditional one ('I'll try hard *if it works well* after the start', '*if it is* not too cold', '*if I am* lucky with wax', etc.).

Focusing attention on body signals (association) or on the external cues (dissociation) is another aspect worth considering in the development of fatigue tolerance in elite skiers. The association–dissociation literature (for a review see Masters & Ogles 1998) indicates that association was correlated with fast times and was used more frequently by elite long distance runners who also train harder. Earlier work on cognitive strategies in elite and non-elite distance runners (Morgan *et al.* 1987, 1988) has indicated that the elite runners were putting in more miles per week and therefore had experienced twice the rate of staleness as the non-elite group. Research on association and dissociation strategies used in running indicates that elite runners tend to dissociate during training but tend to associate to their body signals during marathon. Non-elite athletes tend to dissociate more than associate in general. Association seems a good strategy because it allows monitoring of body signals and responding to signals it is giving. More skilled and experienced athletes are usually more aware of their emotions and body signals accompanying optimal and less than optimal performance. However, deliberately ignoring body signals (e.g. pain) may sometimes be useful and sometimes harmful for the skier.

In the development of endurance, especially during the most demanding and difficult moments of coping with fatigue and pain, elite athletes use different self-regulation (self-stimulation, self-mobilization) skills and strategies. These skills usually include:

1 selection of cues and specific tasks during training ('to ski uphill with the same tempo', 'to do two more laps', etc.); and

2 mobilizational self-talk ('go on', 'just do it', 'keep the rhythm', etc.).

Here it is important to realize that positive, negative and instructional self-talk can have both functionally helpful and detrimental effects upon the emotional states and performance of skiers. Such volitional qualities as goal-orientedness, persistence and toughness, as well as a systematic use of psychological mechanisms of effective recovery, can enhance endurance and high quality training in skiing.

Attitudes towards intensive exercise and technical skills training

Optimal practices in skiing require that athletes and coaches clearly distinguish between quantitative and qualitative aspects of their work. High quality exercise in practices depends on the skier's available physical resources (strengths and limitations) and task-related attitudes (likes and dislikes, preferences and rejections). It is clear that the higher the resources in a particular skier, the more willing he or she is to do more intensive exercise. In general, if an athlete enjoys doing highly intensive exercise in training, it reflects abundance of his or her physical resources. Although the strengths and limitations in skiers as well as their resources are relatively stable, the ability to recruit these resources and use them effectively is very dynamic and can change from situation to situation.

An athlete's attitude to intensive exercise 'filters' the generation and use of energy in training. There are two types of preferences that can be clearly distinguished in Olympic-level cross country skiers: *positive attitude* (enjoying) and *negative attitude* (disliking intensive exercise, being tired, overstressed and exhausted). Similarly, skiers are distinguished by their positive or negative attitudes towards technical skills in practices and races: some enjoy being skilful, smart and highly technical, others are neutral or perceive this part of their exercise as less attractive than physical work. The first type (positive attitude to physical exercise) usually has abundant physical resources, is more tolerant to intensive training and in important races feels quite positive about physically demanding tracks (e.g. long uphills). The second type is more technically orientated and is more skilful in using his or her often moderate physical resources.

Because positive and negative attitudes can function as either facilitators or inhibitors of high quality exercise in practices and races, their timely diagnosis can be very helpful both for athletes and their coaches. That is why forming positive attitudes towards highly intensive physical exercise or technical skills is crucial in optimizing team preparation. With a positive attitude to intensive exercise, a person can do more intensive exercise and more qualitatively exercise, an athlete's recovery from hard exertion is more effective, and thus overtraining and staleness can be avoided. Negative attitudes to either hard exertion or technical skills training indicate that either an athlete lacks resources or has potential (or past) problems with performance in practices and races.

Creating successful situations in practices and competitions is a practical way to develop positive attitudes to both intensive exercise and technical skills training. However, whatever the attitude is, it is important to make a distinction between the amount of exercise and its quality (efficiency—how well it is done). Moreover, the quality of exercise (compared with its amount) is becoming more and more important as an athlete progresses in his or her career. Therefore, it is useful to identify individual preferences for intensive exercise or technical training related to an athlete's available resources as soon as possible.

One practical way to assess positive (preference) and negative (rejection) attitudes towards physical exercise is to use self-report ratings on a scale (the intensive exercise preference scale, IEPS) developed by Hanin (1993, unpublished data). The scale was used with elite athletes competing in cross country skiing, soccer, sports-orienteering and swimming (Table 6.1). Both trait and state versions of the IEPS scale include a positive (preference) subscale (items 1–7) and a negative subscale (items 8–14). Subtotal scores on each scale range from 0 (almost never) to 28 (almost always) for the IEPS scale trait version. The state scale version is different only in the format of response set (from 0 'not at all' to 28 'very much so') and situation-related instructions. The technical skills preference scale (TSPS) has a similar structure and assesses the extent to which an athlete likes (enjoys) or dislikes (rejects or feels bad about) technical skills training. Subscales identify the magnitude of preferences and rejections and their ratio (predominance of positive or negative attitudes or their relative balance).

These scales can be used as practical tools to monitor current attitudes towards physical exercise and technical skills across different training cycles in the season. Additionally, it is possible to use these scales for team-level analysis to identify skiers who deviate in their attitude towards intensive exercise or technical skills training from the average scores of their teammates (Table 6.1).

Exertion : recovery ratio

High quality training also requires consideration not only of the amount and quality of exercise in practices but also the amount and quality of post-performance recovery. Repeated or prolonged overreaching (or overtraining) is usually considered to be among the major sources of staleness and burn-out in endurance athletes. However, it is more a case of insufficient recovery ('underrecovery') than simply excessive exercise, and this usually results in an exertion : recovery imbalance causing problems in the preparation of top-level skiers. Moreover, athletes and coaches until quite recently did not consider recovery as an integral part of the performance process and as a result skiers did not systematically use recovery

Table 6.1 Intensive exercise preference scale (IEPS trait).

Intensive and stressful exercise is a part of training in sports. All athletes have to do it to improve their performance. However, it is well known that some athletes feel quite good about performing intensive exercise, while others feel not so good about it.

Please indicate on each of the items listed below how often do you feel this way about intensive and stressful exertion in your training. Use the following scale:
A almost always (4 points)
B often (3 points)
C sometimes (2 points)
D seldom (1 point)
E almost never (0 point)

Rating

1 I enjoy doing intensive exercise
2 I prefer doing a large amount of exercise
3 I like getting really tired
4 I feel good when overstressed
5 I enjoy exercising under pressure
6 I feel satisfied after really hard exercise
7 Hard and intensive exercise is very important for me

Subtotal P = ___

Rating

8 I dislike doing intensive exercise
9 I dislike doing a large amount of exercise
10 I dislike getting too tired
11 I feel unwell when overstressed
12 I dislike exercising under pressure
13 I feel dissatisfied after really hard exercise
14 Hard and intensive exercise is not very important for me

Subtotal N = ___

Total = Subtotal P/(Subtotal P + Subtotal N)

Note: Subtotal scores for patterns of positive attitude or preferences (items 1–7) and negative attitude or rejections (items 8–14) range from 0 ('almost never') to 28 ('almost always').

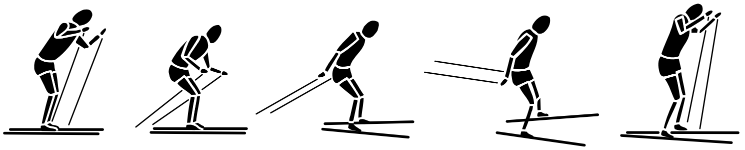
methods and means known and available to them. Therefore, it is good to start with listing all available methods known to a particular athlete (or athletes) and to compare this list with the recovery strategies used by other top performers. Monitoring an exertion : recovery ratio during a week prior to races and then contrasting it with the results of the race can be quite illuminating. For instance, the athlete may know that he or she should use recovery but for some reason does not use it because the idea of exertion : recovery balance has not become a part of his or her professional attitude towards preparation. Several assessments of individual dynamics of the exertion : recovery ratio during the season (or part of the season) are especially helpful in implementing the principle of high quality training. An example of a brief checklist for monitoring situational (relatively stable, accumulated) scores of exertion : recovery ratio that has been successfully applied in swimming, soccer, ice hockey (and partly in skiing) is shown in Table 6.2.

Optimal and dysfunctional performance states in skiers

Situational performance states are one of the most important factors that can affect the quality and consistency of skiers' performances in training practices and races. Stress-related research in sport psychology has focused mainly on the analysis and description of specific dysfunctional states impairing performance rather than on optimal states enhancing performance.

The dysfunctional performance states include such conditions as, 'hitting the wall', 'monotony' and 'oversaturation'. Physiological and psychological markers of these states as well as their different stages have been identified and several preventive strategies suggested (see Chapter 5, section on Overreaching and recovery from training). Successful preventive strategies include a gradual increase in training intensities, careful warm-up before each training session, planning energy utilization during the race, avoiding too quick a start in the race, and active recovery during the race. Again, exertion : recovery balance is a key concept in better understanding and preventing such dysfunctional states.

Recently, more attention has been given to optimal emotional states (positive and negative emotions) that are helpful for skiers' performance in training



Exertion : recovery ratio Date: Name:

Exercise/intensity

My training (yesterday) went well and I feel I am making good progress

0 1 2 3 4 5 6 7 8 9 10

How stressful do you perceive yesterday's practice?

Physically

0 1 2 3 4 5 6 7 8 9 10

Psychologically

0 1 2 3 4 5 6 7 8 9 10

How energetic did you feel during yesterday's practice?

Physically

0 1 2 3 4 5 6 7 8 9 10

Psychologically

0 1 2 3 4 5 6 7 8 9 10

Recovery

How well did you recover during the last 24 h after the last practice?

Food, drinks—balance

0 1 2 3 4 5 6 7 8 9 10

Muscle treatment (e.g. stretching, warm-up, morning run)

0 1 2 3 4 5 6 7 8 9 10

Relaxation and rest, having fun

0 1 2 3 4 5 6 7 8 9 10

Sleep (last night) and other rest

0 1 2 3 4 5 6 7 8 9 10

How energetic do you feel now?

Physically

0 1 2 3 4 5 6 7 8 9 10

Psychologically

0 1 2 3 4 5 6 7 8 9 10

It is easy to go to the next training session

0 1 2 3 4 5 6 7 8 9 10

Table 6.2 An exertion : recovery ratio checklist. Rating scale: 0, not at all; 10, very much so.

practices and competitions. Specifically, it was found that in practices (intense exercise and technical skills training) and in races both pleasant (positive) and unpleasant (negative) emotions could be helpful. Skiers usually perceive strong energy-producing emotions, such as 'motivated', 'charged', 'rested', 'purposeful', 'energetic', 'willing' and 'confident' as pleasant and helpful. These emotions are experienced when athletes perceive the race or the task at hand as a challenge, which they can handle with sufficient resources. Negative emotions such as 'tense', 'dissatisfied', 'nervous', 'tight', 'uncertain', 'irritated' and 'attacking' are also perceived as strong and helpful emotions. Negative emotions are triggered by a threat of loss, anticipation that task demands are too high or available resources insufficient for such a task. In both cases emotions indirectly reflect an athlete's anticipation of consequences of the current situation and a skier's high or low readiness to mobilize available resources. In the case of insufficient recovery, low health status or injuries, unpleasant emotions are especially important as they have a compensatory function in recruiting emergency resources.

As to the situational dysfunctional effects of task-related states, both negative and positive emotions can be harmful for athletic performance. Feelings of being 'tired', 'unwilling', 'depressed', 'distressed', 'sorrowful', 'exhausted' and 'lazy' usually reflect a lack of resources or a difficulty in their recruitment and utilization, and a clear need for recovery. However, some pleasant emotions can also be harmful, especially prior to and during performance, if they reflect complacency, too much satisfaction and low action readiness. In skiing, these emotions related to overemphasis on past successes include subjective feelings of being too 'easy-going', 'animated', 'satisfied', 'pleasant', 'excited', 'comfortable' and 'certain'. Detrimental effects of such pleasant emotions prior to or during performance are reflected in their demobilizational and demotivational impact and may result in a sudden drop in action readiness and premature discontinuation of activity.

Each skier usually has his or her own constellation of optimal and dysfunctional emotions—emotional profile—for races, intensive exercise and technical skills training. Skiers usually experience stronger emotions in races and intensive training, which require more energy than technical skills training. Especially helpful in technical skills training are such feelings as 'eager', 'rested', 'motivated' and 'enthusiastic'. Additionally, some unpleasant emotions of moderate intensity such as 'dissatisfied', 'uncertain', 'concerned' and 'doubtful' can also help to keep the right focus and to stay on the task. However, 'fatigue' and 'complacency' are usually detrimental for high-quality performance in practices and races. Each skier has a unique constellation of optimal and dysfunctional emotions for practices and races that produce effective or less than effective focus and energy/activation level.

Emotional markers of individually optimal and dysfunctional states can be useful indicators after intensive exercise or after very demanding successful or unsuccessful races as early signs that, for instance, more recovery is needed. Chronic deviations from optimal zones of intensity serve as reliable indicators in prevention and treatment of staleness in skiers.

Main points to remember about psychological factors affecting high quality training in skiers

- Positive attitude towards physical exercise of high intensity and volume.
- Awareness of body signals and emotions related to optimal performance.
- Positive attitude to performance-induced fatigue and pain.
- Awareness and active acceptance of need for high exercise intensities.
- Categorical (unconditional) mind-set in planning task execution or race strategy.
- Flexibility in using association–dissociation skills.
- Using on-task self-regulation skills (relaxation, positive and negative self-talk).

Consistently successful performance in ski-races

Effective practices are only one important part in the preparation for successful and consistent pre-performance during the season(s). Much also depends on how consistently skiers follow their effective performance routines and strategies in preparing for each race, based on earlier goal-setting for the season. The whole picture of the entire competitive season is important as a basis for setting up specific goals for each race in the season. In the sections that follow a brief description of selected pre-, mid- and post-race analyses are provided.

Preparing for the race

The main emphasis during the week prior to the race is to enhance self-confidence and to try out some elements of the race: competitive speed, rhythm of the race, the entire race strategy, and to make sure that physically, technically and psychologically a skier is ready for the race. Of utmost importance in the pre-race practices is the exertion : recovery balance and generating the willingness to participate in the race. It is useful to model the track profile and the race rhythm of the forthcoming competition in training. Here again, following the usual preparation routines adds to a skier's self-confidence.

Self-confidence in skiers is greatly enhanced if they follow usual preparation routines in pre-race practices a week before the race and carefully plan their behaviour and performance on the day of the race. To illustrate this point a description of a typical training day during the last week should include answers to the following questions.

- When did you wake up?
- When did you prepare your skis?
- When were your first and second training sessions and what kind of sessions were they?
- When did you have your meals and drinks?
- When did you have a nap?
- When did you stretch?
- When did you read and watch television?
- When did you analyse technical performance from video recordings?

Routines on the day of the race are also important to create an optimal performance-related state. Below is an example of how an elite skier should organize his or her typical racing day.

1 On the evening before the race:
- track analysis—three times (if a new track), downhills, curves, uphills;
- weather forecast, starting time, starting list;
- selecting skis with the service staff;
- getting clothing ready and going to bed—23.00 hours.

2 On the morning of the race day:
- waking up 4 h before the race;
- checking of the weather and snow;
- run/stretch/shower;
- breakfast 3 h before the race.

3 Getting ready for the race:
- resting for a while;
- concentrating on the competition;
- visualizing the race course, especially the difficult sections;
- getting dressed (15 min) and taking fluids (15–20 min).

4 In the skiing area (1.5 h before the race):
- wax-room, testing him or herself or with a service staff member;
- warming up 50–60 min and checking if any changes in the track, downhills;
- slow skiing (50% of race pace) and testing race velocity, including one uphill (3–4 min).

5 Before the start, in the start area:
- changing clothing;
- drinks;
- service staff member brings the racing skis.

6 After the race:
- dry clothing, warm drinks;
- meeting the media;
- warming down and stretching;
- eating and energy drinks;
- race analysis and forgetting the race.

Self-regulation of emotional states during the race

Experienced skiers quickly learn to regulate their performance-related states in races. These self-made self-regulation skills are based on careful listening to body signals and can be quite effective. However, self-regulation is best planned prior to the race. There are several effective strategies to cope with extreme fatigue before it is too late.

The first strategy of *generating energy* is based on strong positive (self-confident, enjoying) and negative emotions (anger, rage, anxiety, fury). These situational emotions are especially useful when they are accompanied by self-empowering thoughts ('I can do it', 'I am strong and quick', 'I am in the best form', 'I am stronger than others', 'I'll beat them all'). Thus, all energy is channelled effectively to the task at hand.

It is important to realize that emotions of similar intensity can demotivate and impair individual performance if they are accompanied by self-defeating thoughts ('I can't do it', 'I am too tired', 'I should stop', 'They are much stronger than myself'). By changing the content of automatic thoughts and self-talk it is possible to channel available energy and efforts.

The second strategy is *emotion shifting* or a *substitute* strategy that involves deliberate generation of strong negative emotions, such as anger, fear and rage, in order to 'squeeze out' the feelings of tiredness. Negative imagery is helpful in postponing fatigue which affects negatively performance, especially during long uphill sections of the track. Shifting strategy can be used repeatedly as a skier begins to feel tired and before the most demanding parts of the track.

The third strategy involves *active recovery during performance* by completely relaxing and recharging one's batteries while on the job. Quick recovery becomes possible after a skier learns to relax quickly by using rhythmic breathing and deliberate relaxation

Fig. 6.1 Active recovery during performance for 15–20 s is sufficient to recover quickly and continue the race at a good speed. Active recovery is especially helpful after a quick start in the race or after demanding exertion in uphills. It is also useful to plan active exercise and recovery phases before the race, based on a pre-race analysis of the track profile. Photo © Agence Zoom/Getty Images.

of hands, legs and the whole body. After a skier has learned the basics of relaxation, 15–20 s is usually sufficient to recover and continue the race at a good speed. Such instant recovery is especially helpful after a quick start in the race or after demanding effort in uphills (Fig. 6.1). It is also useful to plan increased effort and active recovery phases before the race, based on a pre-race analysis of the track profiles.

Whatever strategy is used by the skier, it is important to realize that efficient self-regulation during the race should be based on a skier's ability to listen to the right body signals and to respond to these signals. Two extreme strategies related to association and dissociation are usually less than effective: being too sensitive to body signals by responding to them with self-defeating thoughts and/or trying to ignore these body signals completely.

Post-performance analysis

Every race can provide learning experiences for skiers and their coaches if these experiences are properly recorded and processed. Therefore, it is important to analyse every race in terms of planned and achieved goals, related both to strategies used and to performance outcomes. As there is not much time to do such an analysis immediately after the race, it is recommended that a special time is allocated on the following day (but not later than 2–3 days after the race) to re-examine every important detail of preparation for the race and the skier's behaviour, thoughts, emotions and performance during the race. Such analysis helps to increase awareness of successful and unsuccessful patterns and provides a good basis for more focused preparation for future races. Moreover, a process-orientated analysis also helps to avoid an overemphasis on the outcome of the race, which is usually out of the direct control of the skier.

Main points to remember about psychological factors contributing to consistently successful performance in races

- High quality race-orientated pre-competition practices.
- Effective performance routines.
- Awareness of own optimal states prior to and during races.
- Creating optimal mind-set and effective strategy for the race.
- Using and refining on-task self-regulation skills (prior to and during the race).
- Learning from each race (focused post-performance analysis and debriefing).

Group dynamics and environmental factors

Although cross country skiing is an individual sport, it would be a mistake to ignore or underestimate interpersonal and intragroup processes as well as the environmental influences that could affect skiers' preparation and performance. The skiing team, especially at the national team level, usually includes closely interacting members such as team and personal coaches, service personnel, medical care staff, researchers, team management and parents. The key to successful team performance is cooperation and effective interaction of all participants. Thus, team members do their own job the best way they can and contribute to the team's success by effectively communicating and cooperating with others. Crucial in these interactions is the contact between national team and personal coaches, coaches and athletes, service personnel and athletes, and physicians and athletes (Fig. 6.2). Therefore, it is good from the very beginning to realize that all participants aspire to the top team and therefore all should be prepared to give performances of high quality and intensity both in practices and races.

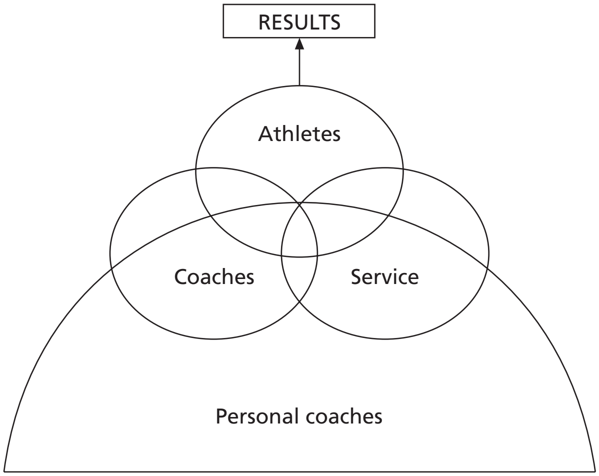


Fig. 6.2 Interaction and communication in a ski team.

Enhancing cooperation and communication in the skiing team

From a sociopsychological perspective, special attention should be given to interpersonal and intragroup influences and team morale. The emphasis should be on developing effective communication and cooperation between team members to avoid potential problems. The contact between team coach and personal coaches, between skiers, between skiers and service personnel, and with skiers' parents are therefore of crucial importance.

Head coach and personal coaches

Personal coaches have often worked with their skiers for years before they have been invited to join the national team. Personal coaches know their skiers and their strengths and limitations, and therefore they are the key people in the psychological preparation of skiers, especially between the camps of the national team. The adaptation of these athletes into the national team can depend very much on how quickly and effectively they are able to adapt to the new demands and conditions.

It is crucial from the very beginning to pay attention to establishing systematic contact between national team coaches and personal coaches, especially in the case of young aspiring athletes joining the team and whom national team coaches do not usually know very well. Therefore, effective two-way communication is important here so that personal coaches can provide details not known to national team coaches about specific responses of young skiers to training regimens, their best ways of recovery, preferences and dislikes, etc. National coaches can provide important feedback to personal coaches about their athletes by describing how well the athletes adapted in the team, what are the tasks for the next stage in team preparation, and also about the expectations for and during the season. This communication serves an important motivational function for both personal coaches and for athletes. The basic issue here is to establish and maintain systematic contact in order to develop optimal working relationships in the team, which are usually spontaneous.

Several strategies are available to national team coaches to facilitate and enhance their contact with personal coaches, starting with the first meeting in the team and detailed information about the team's plans, service staff and experts working with the team. Following this initial meeting, further planning can be enhanced by developing a '*matrix of better cooperation*'. Each personal and national team coach in a single group session fills in a list of specific ways he or she can improve his or her own work and cooperation with the head coach, service personnel, physicians and experts working with the team. Such individual lists are then aggregated into a list of current tasks for the head coach for further prioritizing and planning cooperation within the team.

Head coaches usually prefer personal coaches to contact them; however, at the beginning it is best if the national team coach first calls the personal coach. To get personal coaches more involved in the preparation of the national team, they are invited to training camps and competitions and can even serve as temporary coaches for the national team. As soon as working relationships are established, personal coaches are ready to take a more active role. It is the responsibility of the head coach to see that the best facilities and conditions are created for the team; selecting the best performers, and providing the best training conditions to realize athletes' potentials.

Service personnel and skiers

Communication between service personnel and athletes is one of the most important dimensions in almost any top-level cross country ski team, especially during major competitions. For some service personnel it is often really tough work: they start early in the morning (often well before 05.00 hours) and do not finish until late at night. The main workload is the need to handle 2–4 pairs of skis for each of the 6–8 female and 6–8 male skiers. Best performance for service personnel includes timely and sufficient selection and testing of skis and wax and helping skiers get into the right frame of mind and keep focused on winning. Less than satisfactory performance of service personnel is caused by unnecessary rush, lateness and erroneous or ineffective selection of skis and wax, which can distract skiers and disturb their concentration. This depends not so much on service personnel or skiers individually but rather on their cooperation. Well-organized routines, knowledge of the procedures and good working relationships are essential for effective pre-race preparation and post-performance analysis.

Service personnel are usually very experienced and dedicated people who try to do their best in coping with a heavy workload. However, they are less visible than skiers or coaches in the team and their work is often not publicly recognized. Both hidden and overt confrontations, and even conflicts, sometimes emerge: skiers blame the service personnel after unsuccessful races or do not acknowledge their contribution to successful races. As a result, service personnel may feel their work is not appreciated and can be reluctant to share their experiences about ski testing and waxing with the skiers. It should be appreciated that female skiers are usually less active in the preparation of their skis and rely mainly on the experience of their coaches or service personnel. In contrast, male skiers are more interested to learn about the process and overcome the unwillingness of service personnel to share their experiences. Another problem, especially with young skiers in the national team, is that athletes do not always help service personnel to clean skis after practices so the amount of additional work for the service personnel can increase dramatically during training camps where not all service personnel are available.

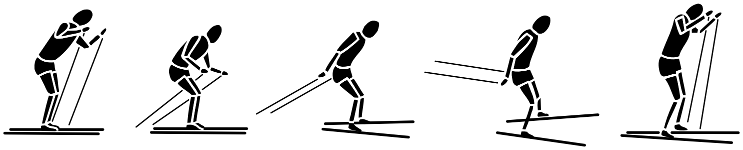
A psychological difficulty is that top-level skiers prefer an individual service from a definite person helping them and in whom they trust. Thus, if working relationships are not established then communication between service personnel and athletes may be non-existent. With no feedback from skiers it is difficult for the service personnel to develop and improve their work. This gap has to be closed by clearly telling both service personnel and athletes what is expected of them. Simple things like arriving on time, actively participating in ski selection and testing, and helping clean up skis can improve contact between service personnel and skiers.

Several strategies can improve communication and group dynamics in the team and between athletes, service personnel and coaches. Special attention should be paid to young skiers (newcomers) and their personal coaches joining the team so that they know more about the team. One form of establishing good working relationships between skiers and service personnel is to provide more information about the work that is done by service personnel, often behind the scenes and therefore not fully recognized. Thus, regular '*experience sharing*' sessions related to ski selection, waxing and testing, with a special emphasis on the best national and international practices in service work could be useful. These sessions should focus on analysis of the best practices of ski preparation and what has worked well in the past and help to open up the channels of communication in the team and develop trust. Following this, items to be improved can be examined in some detail. The role of personal coaches in this is especially important, in sharing their experiences and creating the right attitude in young athletes towards the work of service personnel and in improving cooperation with them. Finally, an important factor to develop optimal working relationships between service personnel and skiers is a post-performance analysis of their joint work. A simple but well-structured checklist may be helpful in constructive evaluation of such cooperation and may enhance communication in the ski team (Table 6.3).

Coaches and skiers

Two-way open communication between national team coaches and skiers is no doubt one of the most important factors for effective preparation of the team and its successful and consistent performance. Effective contact between the coaches, team leaders and young skiers are established and maintained during and between the camps and major races of the season. A head coach works with the team via

Table 6.3 Checklist of quality of ski service in races. Rating scale: 0, extremely bad; 1, very bad; 2, bad; 3, good; 4, very good; 5, extremely good.



Skier's name: Place: Date:

Day before the competition						
1 Preparing skis selected for testing	0	1	2	3	4	5
2 Testing skis	0	1	2	3	4	5
3 Testing the place	0	1	2	3	4	5
4 Cleaning and basic preparation of the selected skis	0	1	2	3	4	5
5 Selecting the skis for a race	0	1	2	3	4	5
6 Service session	0	1	2	3	4	5
Day of competition						
Before the race						
1 Arrival at service place and instructions	0	1	2	3	4	5
2 Waxing the skis	0	1	2	3	4	5
3 Selection of skis	0	1	2	3	4	5
4 Testing the place	0	1	2	3	4	5
5 Final preparation	0	1	2	3	4	5
During the race						
1 Preparation in the starting area	0	1	2	3	4	5
2 Ski quality (pair number)	0	1	2	3	4	5
(a) Hold	0	1	2	3	4	5
(b) Slipper	0	1	2	3	4	5
(c) Skiable	0	1	2	3	4	5
3 Intermediate times	0	1	2	3	4	5
4 Drinking place	0	1	2	3	4	5
5 Other track service	0	1	2	3	4	5
6 Performance at the finish	0	1	2	3	4	5
After the race						
1 Giving feedback	0	1	2	3	4	5
2 Cleaning and waxing the skies	0	1	2	3	4	5

What was really good?

What could be improved?

team meetings and individual contact with the skiers prior to, during and after training sessions. A coach's timely feedback and support is very important for an athlete's progress and successful coping with problem situations during the season (unsuccessful races, sickness, injuries, problems outside the sport setting).

Good working relationships with the best skiers (team leaders) are important for creating a supportive and professional atmosphere in the team, especially for a new head coach. The role of personal coaches and parents is very important in developing these relationships, especially with new members and young talented skiers to help them adapt successfully in the team. This is even more important in cases when the young skier is shy and does not initiate and develop such relationships; here the coach should be very sensitive to his or her needs in special feedback and support.

Experience shows that it is useful to monitor the team's preparation by regular assessment of progress in particular areas and screening for potential problems. Analysis of current needs and athletes' perceptions of what is working well and what needs further improvement in coaching, travel and accommodation, service and medical care are examples of areas that can be regularly assessed at the beginning, during and at the end of the season. Such team-building sessions are especially important if a new coach or a new staff member (e.g. a physician or head of service personnel) joins the team. The feedback from skiers on 'what worked well' and 'what needs further development' in this case could be instrumental for improved adoption of new members into the team and in developing the best practices within the team. The working relationships of the national team coaches with the skiers already selected to the team (and promising candidates) can also be greatly enhanced through regular contact (phone or e-mail) between the camps. Such communication with skiers and their personal coaches is highly motivational and helps the head coach to influence the process of individual and team preparation during the season by enhancing the team-building process.

Relationships between skiers

Any national-level ski team includes both young athletes (newcomers) and old-timers with considerable sporting experience, and good working relationships between these two groups are not always created automatically. Much depends on the predominant value system, psychological climate/atmosphere in the team, and specifics of status/role relationships in the team. Problems may arise not only related to age differences, but also to the head coach's attitudes, and past experiences of old-timers with adaptations to the team. Different systems can work effectively for different people. For instance, a clear distinction between young skiers and old-timers might be stimulating and helpful for some athletes, but more open, supporting and friendly relationships might be preferable for other skiers. The notion that newcomers 'should learn their place in the national team' in a tough competition is still a widespread reality for personal and head coaches. Therefore, a head coach planning a camp has to consider the adaptation and relationships between young and old skiers, as well as between female and male skiers, as important factors which can influence the effectiveness of team preparation for the major races of the season.

Main points to remember about social psychological factors affecting skiing performance

- Interpersonal, intragroup and environmental influences.
- Cooperation and communication between coaches, athletes, service personnel and staff.
- Team morale and existing norms of exercise and life in the team.
- Optimal relationships reinforcing the achievement of individual and team goals.
- Active participation of team members in decision making.

Stress and burn-out in ski coaches

Coaching elite skiers requires multiple skills to handle different tasks (contacts with various people, planning practices and competition, presentations) under considerable pressure from the media and sports federations. These pressures are never-ending and create a chronic imbalance between situational demands and the available resources. Such chronic stress in coaches often leads to burn-out (emotional exhaustion, emptiness, decreased motivation, insomnia, feelings of helplessness, poor work performance).

Until quite recently most research in sport psychology was directed towards examining and understanding competitive stress, burn-out and overtraining in athletes but now there is a growing consensus that more research into stress and burn-out of elite coaches is also needed. A practical approach is to alert coaches to the need to monitor their exertion : recovery balance. Stress and pressures are a part of their daily work and effective adaptation depends on coaches' readiness to cope with their heavy workload by paying more attention to recovery.

Another problem for head coaches working with national teams is the relative loneliness often found in managerial roles, and the lack of a consistent personal and professional support team. Experience has shown that it is most helpful for elite ski coaches to have regular individual briefing/debriefing sessions during the season with a sport psychologist. Such 'developmental talks' are very effective for processing the current situation and the coach's experiences by examining them from a wider perspective. A sport psychologist can help a coach to reframe and restructure stressful situations and thus avoid chronic stress. Organizing the optimal sociopsychological climate in the team and effective contact with the environment, distribution (delegation) and better coordination of team preparation are the best strategies in the prevention of excessive stress and burn-out in coaches and athletes. It is important to realize that, in the Olympic cycle, stress and burn-out can accumulate gradually so a coach who starts his or her work with the new team typically does not notice the stress and pressures during the first 2 years, especially if the team is successful. The third season or even the beginning of the fourth season is usually the most difficult and a coach, even in a successful team, can experience most difficulties and burn-out right at the beginning of the Olympic season, with no visible reasons for a potential breakdown. Therefore, all the recommendations for high quality practices and active recovery suggested earlier for athletes also apply to their coaches. It is important that a coach uses these principles him or herself and sets a good example for the skiers. This area requires additional research, especially in view of the increased international mobility of elite ski coaches invited to work with national teams in different countries.

Conclusions

This chapter briefly reviews the psychological factors that can affect the effectiveness of practices and races in high-level cross country skiers and coaches in national and Olympic teams. It must be emphasized that psychological preparation is an integral part of high-quality practices and consistent successful performance in international races. Therefore, psychological aspects of working with high-level skiers should be incorporated into their physical, technical and tactical preparation. The role of sociopsychological (group dynamic) factors is highlighted and the selected strategies of self-regulation of performance-related states are discussed. Finally, the importance of preventing and coping with excessive stress and burn-out in elite ski coaches is substantiated.

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