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# Nutrition for winter sports

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**Abstract**

Winter sports are played in cold conditions on ice or snow and often at moderate to high altitude. The most important nutritional challenges for winter sport athletes exposed to environmental extremes include increased energy expenditure, accelerated muscle and liver glycogen utilization, exacerbated fluid loss, and increased iron turnover. Winter sports, however, vary greatly regarding their nutritional requirements due to variable physiological and physique characteristics, energy and substrate demands, and environmental training and competition conditions. What most winter sport athletes have in common is a relatively lean physique and high-intensity training periods, thus they require greater energy and nutrient intakes, along with adequate food and fluid before, during, and after training. Event fuelling is most challenging for cross-country skiers competing in long events, ski jumpers aiming to reduce their body weight, and those winter sport athletes incurring repeated qualification rounds and heats. These athletes need to ensure carbohydrate availability throughout competition. Finally, winter sport athletes may benefit from dietary and sport supplements; however, attention should be paid to safety and efficacy if supplementation is considered.

**Keywords:** *Altitude, cold, skiing, skating, energy*

## Introduction

Winter sports are pursuits played during the winter season on snow or ice. The Olympic movement included winter sports for the first time in Chamonix in 1924, with 258 participants from 16 nations. Today, winter sport Olympians are outnumbered by about one to four by summer Olympians. Nevertheless, the 2010 Vancouver Olympics reported the highest number of athletes and events at any one Winter Olympiad. This paper will first discuss the winter sport specific environment, altitude and cold, followed by an applied section emphasizing the specific nutrition issues faced by winter sport athletes.

## Nutritional implications of altitude and cold

Winter sport athletes often encounter altitude and cold during competition or training. These athletes may also use a variety of strategies to promote acclimatization to higher elevations or to improve sea-level performance (Chapman, Stickford, & Levine, 2010). Winter sports conducted in an outdoor environment experience temperatures ranging from –25 to +5°C, while those performed indoors on ice have average temperatures of 5–10°C. Many winter sports are dependent on permanent snow located at higher altitude (glacier) or the southern hemisphere for sport-specific training in the summer and fall and for early-season competition. Glacier environments are located at moderate (2000–3000 m) to high (3000–5000 m) altitudes. In the winter, cold, altitude, and changing snow/ice conditions are characteristic of most competitive venues, as competitions typically occur at northern latitudes and altitudes between 500 m and 2000 m.

For several winter sports, the most challenging period of training occurs when athletes perform high-intensity training in the cold at altitude, on-snow or on-ice in late summer and early fall. Training under these conditions results in a compounding of environmental stresses and metabolic challenges that carry a number of nutritional implications.

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*Altitude*

Upon ascent to altitude, energy expenditure increases. At 4300 m basal metabolic rate increases on average by 10–17% compared with sea level (Butterfield, 1999; Mawson et al., 2000). Altitude exposure is frequently accompanied by weight loss (Hoyt et al., 1994), averaging ~1.4 kg per week (Butterfield, 1996). At altitudes ≥3500 m, appetite suppression can also contribute to weight loss (Kayser, 1992). Weight loss as a result of an energy deficit increases the use of protein as metabolic fuel, leading to a negative nitrogen balance and loss of lean tissue (Kayser, Acheson, Decombaz, Fern, & Cerretelli, 1992). Matching energy intake to the increased energy requirement minimizes weight loss and maintains nitrogen balance at 4300 m, at least in controlled laboratory experiments (Butterfield et al., 1992; Mawson et al., 2000). In addition, carbohydrate supplementation in an energy-deficient state improves performance at altitude (Fulco et al., 2005). Thus, athletes training at altitude can probably maintain weight and preserve muscle mass if adequate energy and carbohydrate are consumed (Kayser et al., 1992).

Substrate utilization at high altitude shifts to greater use of blood glucose at rest and during exercise compared with sea level (Brooks et al., 1991a, 1991b), due to hypoxia increasing the expression of GLUT4 (Brooks et al., 1992). The predominant use of blood glucose, without a concomitant sparing effect of muscle glycogen (Green, Sutton, Young, Cymerman, & Houston, 1989), represents a challenge for athletes training in these environments, as glucose and glycogen quickly become a limiting fuel source. Metabolically, women respond differently to altitude than men, relying on fat as fuel to a greater extent at rest and during submaximal exercise, and women use less blood glucose and glycogen at altitude (Braun et al., 1998).

Early during exposure to altitude, plasma volume decreases, resulting in increased haemoglobin concentration. With continued exposure, red cell mass rises (Martin, Levett, Grocott, & Montgomery, 2010). Erythropoietin is responsible for the production and release of reticulocytes from bone marrow, which contributes to the increase in red cell mass, blood volume, and enhanced oxygen carrying capacity. Iron is an integral part of haemoglobin, so individuals with low iron stores have difficulty producing erythrocytes in sufficient quantity and maturity (Nielsen & Nachtigall, 1998). With altitude exposure, low iron stores will interfere with an effective haematological adaptation (Stray-Gundersen, Hochstein, deLemos, & Levine, 1992). Many winter sport athletes are naturally exposed to altitude, due to their reliance on snow for sport-specific training. Nordic skiers and long-track speed skaters frequently use live-high/train-low strategies, sleeping at moderate altitude (2000–2500 m) and training at lower elevations (1500 m) over the course of 3–4 weeks to optimize haematological adaptations and improve sea-level performance (Wilber, 2007). It is imperative to commence this training with adequate iron status.

Altitude exposure results in a reduction in total body water. Altitude-induced diuresis and reduced thirst during the initial hours at altitude may set the stage for dehydration. Furthermore, increased ventilation and the low humidity of atmospheric air lead to greater respiratory water loss at altitude. Respiratory water loss at altitude may be twice as high as at sea level; theoretical calculations for 24-h respiratory water loss approach 1 $L \cdot day^{-1}$ in addition to fluids lost through sweat and urine (Milledge, 1992). Respiratory water loss can be as high as 1.9 $L \cdot day^{-1}$ in men (Butterfield et al., 1992) and 850 $mL \cdot day^{-1}$ in women (Mawson et al., 2000). Wilber (2004) suggested fluid intakes of 4-5 $L \cdot day^{-1}$ in athletes training at altitude, while even higher recommendations may apply to cross-country skiers (Ekblom & Bergh, 2000.)

*Cold*

Work in the cold may increase energy requirements. Most of this increase depends on whether thermoregulation can maintain skin and core temperature via protective clothing, physiologic responses such as vasoconstriction and reduced blood flow to peripheral tissues, or metabolic heat production due to exercise (Castellani et al., 2006). Factors, in addition to ambient temperature, including wind chill, UV radiation, and humidity can influence the physiologic strain of defending core temperature in the cold (Sawka, Convertino, Eichner, Schnieder, & Young, 2000). When cold exposure is severe enough to elicit a shivering response, energy requirements rise, at least doubling metabolic heat production to maintain core temperature (Castellani et al., 2001). Few winter sport athletes experience shivering when training in the cold because they are able to maintain core temperature. Should shivering occur, however, carbohydrate oxidation is elevated (Vallerand, Zamecnik, & Jacobs, 1995). (For an excellent review, see Haman, Blondin, Imbeault, & Maneshi, 2010).

During exercise in cold environments, individuals often lose 3–8% of their body weight. Reasons for this include large sweat losses, respiratory water loss, cold-induced diuresis, impaired thirst, and limited access to fluids (Freund & Sawka, 1996) with few restrooms (Meyer et al., 1999), ultimately leading to voluntary hypohydration. Cold-induced fluid loss likely leads to greater water than solute loss (Costill, 1977), which can result in mild vasoconstriction and more severe and prolonged cold stress (O'Brien, Young, & Sawka, 1998). Few data are available on hypohydration and its effect on performance in the cold, but a recent study showed that a 3% hypohydration did not degrade endurance performance in the cold (Cheuvront, Carter, Castellani, & Sawka, 2005). Thus, while exercise in the cold can induce large fluid shifts, performance effects will depend on core and skin temperature.

Taken together, the data on altitude and cold suggest that winter sport athletes need to consider the cumulative effects of cold and altitude on energy expenditure, fuel selection, and fluid loss, while beginning training with good iron status. To evaluate the energy requirement of winter sport athletes at altitude and in the cold, estimates by Consolazio (1966) may be helpful: 45–55 kcal $\cdot$ kg$^{-1}$ $\cdot$ day$^{-1}$ for moderate physical activities and 53–68 kcal $\cdot$ kg$^{-1}$ $\cdot$ day$^{-1}$ for heavy physical activities. These values are in agreement with doubly-labelled water studies (Ekelund, Yngve, Westerterp, & Sjostrom, 2002; Sjödin, Andersson, Hogberg, & Westerterp, 1994) and 24-h activity records in winter sport athletes training intensely on snow and ice (N.L. Meyer, unpublished data; Meyer et al., 1999).

Most research on altitude is conducted at high elevations, with limited studies examining nutrition issues in winter sport athletes exposed to their training environments, such as live-high/train-low or live-low/train high intermittently. It should also be noted that elevations exceeding 3500 m may negatively affect sleep (Kinsman et al., 2005) and immune function (Mazzeo, 2005). Despite the fact that elite winter sport athletes are probably highly accustomed to these routines, individual variations and responses should be considered.

Some winter sports are performed indoors in ice arenas and/or at sea level. Nutritional implications for these athletes should centre on similar concepts of maintaining energy and carbohydrate availability and fluid balance.

## Winter sport-specific nutrition issues

### *Physique of winter sport athletes*

Winter sport athletes span the full spectrum of physiques, since sports are uniquely diverse in their physiological demand and movement patterns relative to gravity. Higher or longer jumps receive greater scores and/or technical merit, and jumping is facilitated by lightness and leanness (Monsma & Malina, 2005). In cross-country skiing, lighter skiers may have an advantage on a hilly and poorly gliding course, whereas heavier skiers may have an advantage on a flat course. Cross-country skiing sprint events have shifted the focus to greater lean body mass, strength, and power (Larsson & Henriksson-Larsen, 2008). Alpine skiers, snowboarders, and sledding sport athletes can utilize gravity to their advantage in gaining speed.

Lean and muscular physiques are also common in ice hockey players (Montgomery, 1988) and speed skaters. As with other winter sports, the physiques of long-track speed skaters have changed, with athletes becoming leaner and more muscular (Meyer et al., 2004). There are a number of reviews that provide more information on physique in winter sports (Agostini, 2000; Foster, de Koning, Rundell, & Snyder, 2000; Meyer & Parker-Simmons, 2009; Orvanova, 1987).

Achieving and maintaining a low body weight and/or lean physique is an important issue in winter sports, but may come with severe health consequences. The effects of altitude and cold may compound suboptimal fuelling and result in glycogen depletion and hypoglycaemia, interfering with concentration and increasing injury risk, especially late during the day (Brouns, Saris, & Ten Hoor, 1986). Restrictive eating may also affect training adaptation and can negatively influence reproductive and bone health (Nattiv et al., 2007). While physique concerns and heightened risk of eating disorders exist in several winter sports, they are highest in figure skating, freestyle aerials, cross-country skiing, biathlon, and ski jumping/Nordic combined (N. L. Meyer, unpublished data; Torstveit & Sundgot-Borgen, 2005).

### *Training nutrition for winter sport athletes*

This section will focus on training nutrition, highlighting the most important nutritional issues for winter sport athletes. For more information on training for winter sports, see Meyer and Parker-Simmons (2009).

#### 1. Meeting high energy demands

*Nordic sports.* Of all winter sports athletes, cross-country skiers report the highest energy expenditures. At the extreme, a 50-km racer expends between 13 and 15 MJ (3107–3585 kcal) for the race. During intense, on-snow training, daily energy expenditure of cross-country skiers ranges from 20 to 25 MJ $\cdot$ day$^{-1}$ (4780 to 5975 kcal $\cdot$ day$^{-1}$) (Ekblom & Bergh, 2000). Such high energy expenditures are due to the large muscle mass involved in cross-country skiing. Sjödin et al. (1994) studied male and female cross-country skiers during a one-week, on-snow training camp using doubly-labelled water. Energy expenditure ranged from 15.1 to 20.2 MJ $\cdot$ day$^{-1}$ (3609 to 4838 kcal $\cdot$ day$^{-1}$) in females and

25.4 to 34.9 MJ · day$^{-1}$ (6070 to 8341 kcal · day$^{-1}$) in males. Interestingly, these athletes maintained energy balance and body weight over the course of the study. Thus, athletes can meet high energy requirements by ingesting adequate quantities of food. Of interest is that daily energy intake did not correlate with training minutes. In fact, these athletes consumed an average of 335 kJ · kg$^{-1}$ · day$^{-1}$ (80 kcal · kg$^{-1}$ · day$^{-1}$) with little day-to-day variability, despite changing intensity and volume (Sjödin et al., 1994). Thus, cross-country skiers should focus on ensuring high energy intakes throughout the duration of intense training camps, especially at altitude, to meet high energy demands.

Energy requirements differ greatly among Nordic sports. Ski jumpers have the lowest energy requirements (<8.4 MJ · day$^{-1}$; S. Parker-Simmons, unpublished data), whereas cross-country skiers have the highest, with Nordic combined athletes falling in the middle. Biathletes have high energy demands, similar to those of cross-country skiers, but they compete in shorter distances. However, biathletes are challenged by the task of concentration when aiming for targets during the shooting portion of the event and incur an additional energy cost from carrying a rifle weighing 3.5 kg (Rundell & Szmedra, 1998). Adjusting energy intake to meet variable energy demands poses difficulty to many athletes, particularly female skiers (Fogelholm et al., 1992). Sports dietitians should teach skiers how to prepare for and recover from training in environmental extremes through adequate energy and nutrient intakes.

*Alpine, freestyle and snowboarding.* Alpine, freestyle skiers (e.g. freestyle moguls), and snowboarders (e.g. alpine) are challenged with frequent travel and involuntary "sleep-high/train-high" conditions. Energy needs range from 188 to 230 kJ · kg$^{-1}$ · day$^{-1}$ (45 to 55 kcal · kg$^{-1}$ · day$^{-1}$) for both men and women, not accounting for altitude and cold (Meyer & Parker-Simmons, 2009). Under shivering conditions and at altitude, energy expenditure likely exceeds 230 kJ · kg$^{-1}$ · day$^{-1}$ (55 kcal · kg$^{-1}$ · day$^{-1}$). It is recommended to adjust resting energy expenditure to altitude and increase energy intake by an extra 200–300 kcal · day$^{-1}$ (Butterfield, 1996). In addition, athletes' body weight, appetite, and sleep should be monitored. Energy demands within disciplines of skiing and snowboarding vary. Freestyle aerialists and halfpipe snowboarders cover a shorter course or focus on refining jumps and tricks; thus, energy expenditure is lower. These athletes often have little knowledge and skill to adjust energy and nutrient intakes to their periodized training plan (Meyer et al., 1999; N. L. Meyer, unpublished data).

*Speed skating, ice hockey, and sledding.* No data are available on energy expenditure in these sports except for long-track speed skating. Energy demands for training in speed skating are high. Using doubly-labelled water, daily energy expenditure in male junior long-track skaters ranged from 12.8 to 25.0 MJ · day$^{-1}$ (3059 to 5975 kcal · day$^{-1}$), with an average of 16.8 ± 3.8 MJ · day$^{-1}$ (4015 ± 908 kcal · day$^{-1}$). Exercise energy expenditure ranged from 3.4 to 13.0 MJ · day$^{-1}$ (812 to 3107 kcal · day$^{-1}$) for high-volume endurance training and from 4 to 12 MJ · day$^{-1}$ (956 to 2868 kcal · day$^{-1}$) for on-ice technique training (Ekelund et al., 2002). Energy expenditure is higher during the most intense training phase and will vary in speed skaters according to sprint, all-around (endurance), and short-track disciplines. For ice hockey and sledding, no data are currently available on energy expenditure.

## 2. Macronutrient needs: Carbohydrate

Carbohydrate requirements in winter sports will vary by sport, training/competition, and environmental conditions.

*Nordic sports.* Glycogen reserves may be a limiting factor in cross-country skiing. Glycogen stores decrease by 30–40% after a 10–15 km race and by nearly 100% after a 50-km race (Rusko, 2003). Cross-country skiers, Nordic combined athletes, and biathletes require daily repletion of carbohydrates. During intense training, daily carbohydrate intakes should be ≥6 g · kg$^{-1}$ · day$^{-1}$ and may need to exceed 10 g · kg$^{-1}$ · day$^{-1}$ (Sjödin et al., 1994). On average, Nordic skiers meet carbohydrate recommendations (Fogelholm et al., 1992; Sjödin et al., 1994). As training exceeds 1–2 h · day$^{-1}$, Nordic skiers are advised to use exogenous carbohydrates during exercise to maintain blood glucose concentration. Carbohydrate ingestion rates and forms (sport drinks, gels, and bars) similar to those recommended for cycling and running (30–60 and up to 90 g · h$^{-1}$) are adequate.

*Alpine, freestyle, and snowboarding.* Athletes in alpine, freestyle skiing (i.e. moguls), and snowboarding will also experience muscle glycogen depletion during on-snow training due to the intermittent nature, supra-maximal intensity, and environmental conditions. A day of giant slalom training reduces muscle glycogen content by 50% (Tesch, 1995; Tesch, Larsson, Eriksson, & Karlsson, 1978), with resynthesis of muscle glycogen dependent on carbohydrate intake (Nygaard et al., 1978). Significant blood occlusion and arterial oxygen desaturation occur during giant slalom skiing, with serum and muscle lactate concentrations after one run ranging from

6 to 15 mmol · L$^{-1}$ and up to 24 mmol · kg$^{-1}$ wet muscle, respectively (Ferguson, 2010; Szmedra, Im, Nioka, Chance, & Rundell, 2001). It is expected that alpine snowboarders experience similar responses, while mogul skiers show somewhat attenuated responses. Thus, these athletes should ingest greater quantities of carbohydrates during on-snow training, especially at altitude and in the cold. Unfortunately, athletes do not practise these recommendations (Meyer et al., 1999; Ronsen, Sundgot-Borgen, & Maehlum, 1999; Schena, Pattini, & Mantovanelli, 1995). While there may be an opportunity to resynthesize muscle glycogen during rest periods, carbohydrate intakes of 7–10 g · kg$^{-1}$ · day$^{-1}$ may be needed to replenish glycogen stores.

Changes in weather often interfere with training schedules on glaciers. Time trials require some winter sport athletes to train in thin body suits at temperatures around –15°C. Shivering thermogenesis can be a side-effect, increasing glycogen utilization and accelerating the onset of fatigue. One concern is that low glycogen stores may predispose an athlete to injury, since many skiing injuries occur late in the day (Brouns et al., 1986).

Coaches, staff, and athletes should be educated about the physiological effects of cold and altitude on food and fluid needs. It is common to see marginal intakes of sport drinks and foods when training at altitude (N. L. Meyer, unpublished data; Meyer et al., 1999). Training under such conditions should ensure that athletes receive carbohydrate-rich meals prior to exercise (Pitsiladis & Maughan, 1999) and carbohydrate and electrolyte-containing sport drinks (8–12% carbohydrate concentration; 15–30 g · h$^{-1}$) and foods during exercise (Galloway, Wootton, Murphy, & Maughan, 2001). While on the hill, warm, carbohydrate-containing fluids should be available at the start or finish of a run.

*Speed skating, ice hockey, and sledding.* For on-ice training, carbohydrate requirements will vary based on sport, training factors, and indoor ice conditions. In continuous and intermittent skating, rates of glycogen utilization are high (Green, 1978; Green, Daub, Painter, & Thomson, 1978). In long-track speed skating, energy contribution varies by event, with shorter events ($\leq$1000 m) relying on more glycolytic than oxidative pathways. The low trunk position is a performance-limiting factor in speed skating (Van Ingen Schenau, de Koning, Bakker, & de Groot, 1996) that decreases blood flow to working muscles (Foster et al., 1999), leading to desaturation of haemoglobin and myoglobin (Rundell, Nioka, & Chance, 1997). Blood lactate accumulation is high in speed skaters (20 mmol · L$^{-1}$) (Foster & de Koning, 1999). Altitude and better ice conditions (e.g. Utah Olympic Oval in Salt Lake City) mean faster ice times and skating turns at faster speeds, potentially increasing carbohydrate needs. Carbohydrate intake should be adjusted to the intensity and volume of training, with higher intakes (6–12 g · kg$^{-1}$ · day$^{-1}$) recommended during high-intensity and/or high-volume periods during on-ice and dry-land training. A higher carbohydrate intake should also be the goal for short-track speed skaters during intense training due to the high frequency of training sessions per day. Ice hockey players also need more carbohydrates during intense training. This intense intermittent sport produces high lactate concentrations and reductions in muscle glycogen stores (Akermark, Jacobs, Rasmusson, & Karlsson, 1996; Green et al., 1978). Thus, carbohydrate recommendations should target at least 6 g · kg$^{-1}$ · day$^{-1}$. In general, skaters do not meet carbohydrate needs during intense training (Houston & Green, 1976; N. L. Meyer, unpublished data). For sledding athletes, carbohydrate intake will depend on the discipline, runs taken, and dry-land training.

Long training sessions on ice are best supported by carbohydrate supplementation. Meyer and Parker-Simmons (2009) recommend athletes ingest at least 30 g of carbohydrate per hour, preferably in the form of a sport drink (5–8% carbohydrate with electrolytes), gels, and bars. Most skaters prefer liquid forms of carbohydrate that are easily ported on the ice. Recovery snacks and solid food are often preferred by athletes transitioning from ice to dry-land training.

Similar to summer sports, the type and timing of carbohydrate ingested should be adjusted to the duration, intensity, and frequency of training. More processed carbohydrate sources may be recommended after exercise to promote timely glycogen resynthesis, especially if several training sessions are planned in close succession. Frequent travel and exposure to altitude and cold may disrupt an athlete's regular bowel movement and cause constipation. Ingesting adequate fibre from fruits and vegetables, wholegrain breads, and cereals should also be part of the training diet.

For most winter sport athletes, replenishment of glycogen stores and repair of muscle tissue is of utmost importance. To ensure quick recovery after intense training in winter sport environments, it is recommended athletes ingest carbohydrates at a rate of 1.2–1.5 g · kg$^{-1}$ · h$^{-1}$ and begin carbohydrate feeding within the first 30 min. This should optimize performance in subsequent sessions, especially if multiple sessions are held. The addition of $\sim$15–20 g of protein promotes muscle protein repair and synthesis (see Phillips & Van Loon, 2011). This is especially important in winter sports with an endurance component, eccentric loading, and an emphasis on lean body mass and/or weight control.

Athletes on an energy budget (e.g. ski jumpers, freestyle aerialists) are advised to integrate recovery nutrition principles into their post-exercise meals. Recovery in winter sport is often delayed, because transportation, weather, drug testing, and press conferences can slow departure from the mountain. Athletes should be prepared for unexpected delays and have recovery foods with them.

Common to winter sports is that intense training phases coincide with changing seasons, travel, altitude and cold exposure, and an increased risk of illness. Considering the frequent cases of upper respiratory tract infections, injuries, mononucleosis, and signs of overtraining, especially observed in Nordic combined (Meyer & Parker-Simmons, 2009) and long-track speed skating (Foster & de Koning, 1999), the emphasis should be on meeting energy and macronutrient needs during this training period. Educating athletes on adjusting energy and carbohydrate to training intensity, and integrating fuelling strategies will promote training adaptation and maintain health. Sports dietitians, in collaboration with an interdisciplinary team, should monitor athletes using valid and reliable recovery parameters.

## 3. Macronutrient needs: Protein

Winter sport athletes need adequate dietary protein ($\sim$1.4–1.7 $g \cdot kg^{-1} \cdot day^{-1}$), especially when training intensity and/or volume increase and energy is restricted for weight loss. On average, most winter sport athletes get adequate protein (Fogelholm et al., 1992; Meyer et al., 1999; Schena et al., 1995; Sjödin et al., 1994). However, ski jumpers have low intakes (Rankinen et al., 1998). When exposed to environmental extremes, winter sport athletes who restrict energy intake or suffer from a loss of appetite should increase energy and carbohydrate but may also benefit from additional protein to preserve lean tissue (Kayser, 1992; Kayser et al., 1992).

## 4. Macronutrient needs: Fat

Fat intake of winter sport athletes ranges from 25 to 40% of total energy intake (1.0 to 1.9 $g \cdot kg^{-1} \cdot day^{-1}$) (Meyer & Parker-Simmons, 2009). Fat intake may be higher in less experienced athletes with lower nutrition knowledge (Ronsen et al., 1999), in cross-country skiers during intense training (Sjödin et al., 1994), and in those sports where a low body weight is not a decisive performance factor (Meyer et al., 1999). Educating athletes on the amount and type of fat and how to balance training meals with flavourful oils, nuts, seeds, and fatty fish should be part of sport nutrition education. Winter sport athletes have similar fat needs to summer athletes, with the exception of the environmental factors; fat is an important energy source during rest and submaximal exercise in the cold, but the effect of cold and altitude on glycogen depletion is probably of greater concern.

### *Fluid balance in winter sport environments*

Some athletes use sport-specific training venues even when snow is not available (e.g. ski jumping, freestyle skiing, snowboarding). Nordic skiers and speed skaters use roller skis and inline skates on asphalt, respectively. Nordic combined and ski-jumping athletes compete in the European Summer Grand Prix and perform between 400 and 600 jumps, wearing winter suits. Thus, fluid requirements in the summer are elevated due to higher sweat rates (Meyer & Parker-Simmons, 2009). In winter sport environments, sweat rates are expected to be lower, but respiratory water loss and diuresis can be significant (O'Brien et al., 1998). Thus, assessing hydration status before the morning session (urine specific gravity) and estimating sweat rates during exercise to target fluid replacement are important strategies in winter sports.

*Nordic sports.* Nordic skiers competing in 15–30 km races typically lose 2–3% of body mass (Ekblom & Bergh, 2000). Seifert and colleagues (Seifert, Luetkemeier, White, & Mino, 1998) investigated the physiological effect of water versus sport drink ingestion during cross-country ski training in collegiate skiers. Results showed a 1.8% loss of body mass after 90 min of skiing. Sport drink-maintained plasma volume minimized urine output and led to lower ratings of perceived exertion compared with water. Therefore, ingesting fluids (especially sport drinks) during training sessions and races lasting longer than 15 km should maintain fluid balance. In addition, carbohydrates in sport drinks maintain glucose availability during prolonged exercise in the cold and/or altitude. Transporting a large volume of fluid onto the ski course and keeping the temperature of the beverages at 10–20°C is difficult. Warm sport drinks may be carried in leak-proof bottles with thermal covers (Meyer & Parker-Simmons, 2009).

*Alpine, freestyle, and snowboarding.* Little is known about fluid balance of skiers and snowboarders. In collegiate alpine skiers, fluid intake of 2 $mL \cdot kg^{-1}$ body mass, ingested after each slalom run (altitude: 2435–3045 m; temperature: $<0$°C), was compared with no fluid intake. In the fluid trial, total fluid intake was 1.2 L during 2 h of slalom training, which maintained body mass, whereas 0.6 kg was lost in the no-fluid trial. Urine output was lower, osmolality higher, and plasma volume changes significantly greater from baseline in the no-fluid trial (Seifert, Lutkemeier, White, Mino, & Miller, unpublished data). Thus, even in relatively short training sessions, fluid shifts do occur. Whether low fluid intakes and hypohydration affect skiing performance is unknown, but they may affect performance in subsequent sessions in warm climates. To support training intensity and prevent excessive dehydration in skiers and snowboarders, athletes are advised to ingest sport drinks with electrolytes at intervals of 15–20 min or as lift-rides and training infrastructure permit.

*Hockey, speed skating, and sledding.* Little is known about hydration levels and needs in speed skating and the sledding sports. Indoor cold exposure can lead to hypohydration (Rintamäki, Makinen, Oksa, & Latvala, 1995). In speed skating, the low trunk position and the inconvenience of interrupting training for the use of restroom facilities may keep athletes from drinking. Unpublished data (N. L. Meyer) for long- and short-track speed skating have shown that both hypohydration and weight loss as well as overhydration and weight gain, are risks that need to be monitored when training on ice. This situation may also apply to sledding athletes.

In ice hockey, sweat rates are high but heat dissipation difficult due to clothing (Green et al., 1978). Strategies to improve body cooling in ice hockey are to wear breathable fabrics, remove gloves and helmet during breaks, and to consume fluids. Recently, average sweat rates of $1.8\ \mathrm{L} \cdot \mathrm{h}^{-1}$ (0.8% body mass loss) were measured in junior players, with a third of them losing more than 1% of body mass and more than half commencing practice hypohydrated (Palmer & Spriet, 2008). A subsequent study investigated the repeatability of field fluid testing in elite hockey players. Results showed that estimates of sweat loss, fluid intake, body mass loss, sweat salt concentrations, and salt loss were reliable. Furthermore, the study demonstrated that athletes who would normally drink water during practice, drank just as much sport drink when it was the only drink available (Palmer, Logan, & Spriet, 2010).

### *Micronutrient needs and supplement use*

Winter sport athletes have unique micronutrient needs that are exacerbated when training is intense, integrates altitude and/or cold, and phases of energy restriction are imposed. The micronutrients of special interest for winter sport athletes are iron, antioxidants, and vitamin D. While the supplementation of certain micronutrients (e.g. iron and vitamin D) may be of benefit if status is low, ingestion of antioxidant supplements in the absence of elevated needs may be counterproductive. Winter sport athletes need to use caution when making decisions related to dietary and sport supplements due to the risk of contamination. Limited dietary/sport supplements may benefit winter sport athletes. These include blood buffers, creatine, and caffeine.

### *Fuelling for competition*

In many winter sports, training and competition are markedly different. While altitude and cold remain challenges throughout the winter, and are compounded by the effect of travel, energy, carbohydrate and fat needs are typically lower because races cover relatively short distances and there is adequate recovery time. Thus, pre-competition nutrition strategies are similar to those used in summer sports; athletes should consume easily digestible, carbohydrate-rich foods and adequate fluids in the days and hours before events. For cross-country skiing events (30–50 km), carbohydrate loading may be useful to maximize glycogen stores. A recent study also identified a potential performance effect from the ingestion of a carbohydrate supplement 45 min before a 20-km cross-country ski race (Francescato & Puntel, 2006).

Multiple events (e.g. long-track speed skating), heats (e.g. sprint cross-country skiing, snowboarding, short-track speed skating, sledding), or tournaments (e.g. ice hockey, curling) will require fuelling strategies aimed at maintaining carbohydrate availability. Furthermore, evening events can be challenging due to colder temperatures and shifts in meal patterns.

For the sport dietitian, ski jumping is particularly challenging since ski jumpers must keep body mass low during the competitive season. The length of time at which their competition weight can be maintained before energy levels, nutritional and immune status, and psychological health decline needs to be individually determined. Regular body composition testing, review of training logs, and experimentation at different weights are required. A few times per year, ski jumpers and Nordic combined athletes may carry out specific dietary manipulation (e.g. reduced energy intake, low-fibre/residue, low sodium) to reduce competition weight. These approaches should minimize health and performance impacts (Meyer & Parker-Simmons, 2009).

Taken together, winter sport athletes need to be prepared to withstand the physiologic and energetic challenges of competition. Athletes should carry foods and fluids for fuelling throughout the course of competition. Foods consumed between runs should include easily digestible, carbohydrate-rich sources. Fluids should be provided by sport drinks or sweetened warm teas. If no fluids or carbohydrate-containing foods are available, the athlete may exhaust muscle glycogen stores and may be unable to maintain racing intensity. Most importantly, winter sport athletes need to focus on recovery, especially if repetitive racing occurs over several days or environmental conditions are severe.

## Summary

Winter sports are unique in that they are undertaken under environmental extremes, which must be considered when planning nutrition programmes for the athletes' periodized training and competition season. Athletes at greatest risk for suboptimal nutrition are those with very high energy demands (e.g. cross-country skiing, Nordic combined, biathlon, and speed skating), those exposed to environmental extremes (e.g. alpine and freestyle skiing, snowboarding, cross-country skiing, biathlon, Nordic combined), and those focused on low body mass and fat (e.g. ski jumping, freestyle aerials, cross-country skiing).



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