Health and performance challenges during sports training and competition in cold weather

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ABSTRACT

Olympic athletes compete and train in diverse cold-weather environments, generally without adverse effects. However, the nature of some sports may increase the risk of cold injuries. This paper provides guidance to enable competition organisers and officials, coaches and athletes to avoid cold-weather injuries. This paper will (1) define potential cold-weather injuries during training and competition and (2) provide risk management guidance to mitigate susceptibility to cold-weather injuries.

INTRODUCTION

Cold weather can create a risk of injury, but people generally tolerate outdoor activities and cold exposure without adverse effects. Tolerance largely reflects the protective advantages provided by modern technology, since human physiological responses defending body-temperature homeostasis during cold exposure are less effective than during heat exposure. For the most part, humans rely on avoidance of cold to mitigate cold injury risk, by either wearing protective clothing or taking shelter. For elite athletes, however, the nature of the competition limits their ability to avoid cold exposure. Athletes will, nevertheless, tolerate even severe cold in pursuit of athletic success. Therefore, officials, organisers and coaches must ensure that the environmental conditions during competition and training do not endanger the health of athletes. This short article will review factors influencing cold injury risk, cold injury prevention strategies and performance for athletes competing and training for Olympic sporting events.

COLD INJURIES

When heat losses exceed heat production, body heat content decreases and peripheral and core temperatures decline. If unchecked, declining body temperatures lead to cold injuries. There are two major types of cold injuries: (1) hypothermia and (2) peripheral tissue injuries.

With whole-body cooling, hypothermia is clinically defined by a core temperature below 35°C. Initial symptoms include shivering, apathy and social withdrawal. As core temperature continues falling below 35°C, confusion, sleepiness or slurred speech occur. At core temperatures below 31°C, there may be changes in cardiac rhythms. Mild hypothermia (core temperature=33–35°C) may be effectively treated with simple rewarming (eg, warm shelter, blankets, clothing, exercise and warm drinks), but more severe hypothermia requires clinical treatment.

Peripheral cold injuries can be divided into freezing and non-freezing injuries. However, non-freezing or cold-wet injuries are not typically a concern for athletes, because these injuries typically require at least 12 h of skin exposure to cold-wet (≤10°C) conditions. On the other hand, freezing injuries, or frostbite, are a potential threat. Frostbite occurs when tissue temperatures fall below 0°C. Frostbite is most common in exposed skin (nose, ears, cheeks and exposed wrists), but can occur in clothed hands and feet. Instantaneous frostbite can occur when skin contacts highly conductive cold objects such as metal, which cause rapid heat loss. The most common initial symptom of frostbite is numbness. During re-warming of frostbitten tissues, pain is significant and re-warming should be clinically supervised for all but the most minor injuries.

Individual factors modifying responses to cold and risk of injury

Laboratory studies suggest that physiological responses for maintaining normal body temperature during cold exposure vary among individuals, and that anthropometric, sex, fitness and acclimatisation differences contribute to that variability.[1] For example, convective heat transfer at the skin surface is the principal heat loss vector in cold-exposed humans;[2] therefore, large individuals lose more body heat in the cold than smaller individuals due to their larger body surface area. However, this effect is somewhat mitigated since a large body mass favours maintenance of a constant temperature by virtue of a greater heat content compared with a small body mass.[3] Additionally, while all body tissues provide insulation, adipose tissue's thermal resistivity is greatest, so individuals with more adipose tissue experience smaller body temperature changes and shiver less during cold exposure than lean individuals.[3] Sex differences in heat flux and thermal balance during cold exposure appear entirely attributable to anthropometric differences between men and women, and there is no definitive evidence of significant sex differences in thermoregulatory responses to cold. Cross-sectional and longitudinal studies suggest that physical training and/or high fitness levels confer little or no thermoregulatory advantages during cold exposure,[3] with the exception that fitter individuals can sustain physical activity and high rates of metabolic heat production longer than less fit individuals. Finally, cold acclimatisation has been shown to produce adjustments in human thermoregulatory responses, but in contrast to heat acclimatisation, thermoregulatory adjustments associated with cold acclimatisation are relatively small, slower to develop and provide little practical advantage for defending body temperature and preventing environmental injury.[3]

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Clothing probably represents the most important modifiable factor influencing the magnitude of physiological strain and environmental injury risk experienced by athletes during cold exposure. Detailed consideration of biophysics and heat-transfer properties of cold-weather athletic clothing is considered elsewhere.[4] Insulation provided by cold-weather clothing adds to insulation provided by body fat and other tissues, so that clothing requirements vary among individuals, and team uniform policies should allow for individual adjustments. In the simplest analysis, the amount of clothing insulation required to maintain comfort and prevent excessive body heat loss during cold-weather activity is determined by the thermal gradient for heat loss (a function of ambient temperature and wind), and rate of exercise thermogenesis (a function of exercise intensity). Decreasing ambient temperature and increasing wind necessitate increasing clothing insulation to prevent excessive body heat loss, while increasing exercise intensity and metabolic rates reduce the insulation required to protect against a fall in body heat. During sports in which exercise intensity is very high, metabolic heat production can be sufficient to prevent a fall in body temperature without the need for heavy clothing, even when air temperature is extremely low. On the other hand, athletes dressed appropriately to achieve thermal balance during cold weather events may be inadequately protected before starting, or after completing the event, so additional clothing may be required at the sites of warm-up and cool-down. Finally, if clothing becomes wet from rain or sweating, insulation may be degraded and evaporative heat loss increased, further compromising protection of body heat content.

EXERCISE IN THE COLD

The most important effects of exercise, at least in terms of how cold exposure affects athletes, are the increases in thermogenesis and peripheral blood flow (skin and muscles). The former tends to balance increased heat loss in cold environments, while the latter exacerbates heat loss by enhancing convective heat transfer from the central core to peripheral shell. The thermogenic response during exercise is usually sufficient to match or exceed heat loss when exercise is performed in air.[2] In contrast during swimming, the greater convective heat transfer coefficient of water compared with air, produces rates of heat loss so great that metabolic heat production during even intense exercise can be insufficient to maintain thermal balance.[2]

A noted physiologist, Dave Bass, once observed, 'man in the cold is not necessarily a cold man'. Whether cold exposure influences physiological responses and strain during exercise depends on whether clothing insulation and exercise thermogenesis are sufficient to balance the rate of body heat loss to the ambient environment. If so, core and skin temperatures will remain elevated such that peripheral vasoconstriction and shivering do not develop, and physiological strain and responses will be the same as in temperate conditions. However, during exercise at intensities too low for metabolic heat production to balance heat loss and prevent shivering, oxygen uptake during exercise will be higher than in warm conditions due to the added metabolic requirements of the shivering muscles.[3]

Strenuous physical training can lead to exertional fatigue, which can be severe in overtraining when strenuous exercise and high levels of energy expenditure are sustained for long periods. In such a state, people have difficulty maintaining sufficiently high energy intake to maintain body energy stores, and muscle and fat loss ensues. Sleep can also be disrupted by intense training. Fatigue due to exertion, sleep restriction and underfeeding impair an individual's ability to maintain thermal balance in the cold,[5] and an anecdotal association between exertional fatigue and susceptibility to hypothermia has also been reported.[6] One explanation proposed is that with fatigue, the exercise intensity and rate of metabolic heat production that can be sustained declines, and core temperature can no longer be defended during cold exposure. When underfeeding is a factor, hypoglycaemia and/or muscle glycogen depletion could develop. Acute hypoglycaemia impairs shivering through a central nervous system effect,[7 8] and decreased peripheral carbohydrate stores contribute to an inability to sustain exercise or shivering, thus constraining thermogenesis during cold exposure.[9] Studies also indicate that shivering and peripheral vasoconstriction responses to cold may be directly affected, that is, impaired, following strenuous exercise, repeated or prolonged cold exposure, or both in combination.[10–13] Whatever the mechanism, fatigue, either acute or chronic, compromises the ability to maintain thermal balance in the cold.

COLD INJURY PREVENTION DURING SPORTS COMPETITION AND TRAINING

Risk management

Successful management of cold stress requires athletes, coaches and competition officials to appreciate the nature of health hazards associated with exercising in cold environments, and employ suitable countermeasures to minimise the risk of hypothermia and frostbite. With proper surveillance and oversight, athletes can compete and train safely in most cold weather environments, and there is usually no need to cancel events. Formal risk management processes have been established to identify potential hazards, contributing factors and effective controls and counter measures for employment before/during/after training and competition to prevent cold injuries to athletes.[14]

Risk management begins by identifying the hazard. The key determinants of the risk of cold injury are the environmental conditions to which the individual is exposed, specifically ambient temperature, wind speed, rain or snow fall rate. Obviously, for athletes competing in or training in temperate or warm environments (indoors or outdoors), the risk of cold injury is nil. Thus, the sports in which cold injury constitutes a real hazard are those competed outdoors during the Winter Olympic Games, that is, Alpine and Nordic skiing, bobsledding, luging, skeleton and snowboarding events. Additionally, long-distance open-water swimming can be a cold injury hazard, since immersion in even moderately cool water can potentially constitute a significant challenge to defending against excessive body cooling. The first step in assessing the risk of cold injury during competition or training for these events is documenting environmental conditions to which the athletes are exposed. Archival weather reports obtained from various public sources indicate that typical competition air temperatures for the 'at-risk' events during the Vancouver, Turin, Salt Lake City and Nagano Winter Olympic games ranged from −5 to 8 °C, whereas somewhat more extreme low temperatures were recorded during the Lillehammer (−19 °C) and Calgary (−15 °C) games. However, those measurements were not necessarily recorded near the event venue, or during the conduct of the events, and there appears to be no official, comprehensive archive of weather data from previous Olympic winter events. Rapidly changing weather conditions are common to regions where Alpine and Nordic sports are competed, so it cannot be

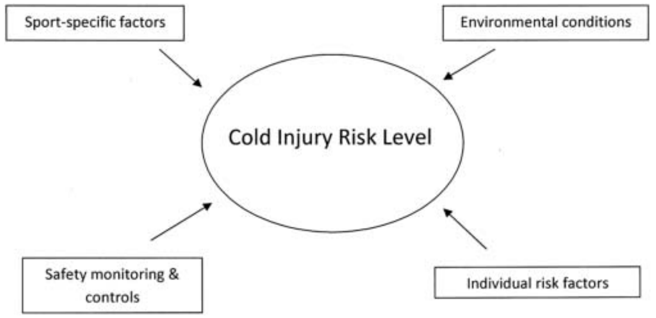

Figure 1 Cold strain risk management process.

assumed that the weather measured at a site distant from the competition accurately represents exposure conditions for competitors, nor can it be assumed that conditions will remain constant throughout the competition. Therefore, a system for continuously measuring, recording and disseminating reliable, real-time weather data at Olympic venues throughout competition should be implemented.

Figure 1 illustrates the factors that positively or negatively modulate cold injury risk for an individual athlete during competition or training. The sport-specific features influencing risk of cold injury to participants in 'at-risk' Olympic events are listed in table 1. As described earlier, whether hypothermia or frostbite can occur during competition or training for these events will depend on the degree to which these factors interact to influence body heat content, and associated changes in body temperatures.

Frostbite prevention

Wind exacerbates convective heat loss[15] and reduces clothing insulation. The Wind Chill Temperature Index (WCTI; figure 2) integrates wind speed and air temperature to provide an estimate of the cooling power of the environment.[16 17] The WCTI standardises the cooling power of the environment to an equivalent air temperature for calm conditions. More precisely, the WCTI quantifies the relative risk of frostbite (compared with skin cooling rate in still air) and predicts times to freezing of exposed facial skin.[18] It should be noted, however, that one of the underlying assumptions inherent to the WCTI is that the individual is sedentary, so WCTI overestimates frostbite risk and underestimates time to skin freezing for individuals exercising strenuously.

While wind facilitates heat exchange between the body and environment, an exposed object (body) cannot cool below ambient temperature. Thus, frostbite cannot occur when air temperature is above 0°C. On the other hand, wind speeds obtained from weather reports do not take into account man-made wind. As shown in table 1, during Alpine and Nordic skiing, snowboarding and sledding, participants move (22–100 km/h), thereby creating wind across the body at that same rate, so the effective wind chill temperature for the moving competitor would be lower, and risk of frostbite higher, compared with non-moving spectators at that same venue. Some Alpine skiing events can generate wind speeds of 100 km/h, but these events last less than 3 min, so the risk of frostbite during those events still does not become high until WCTI reaches −35°C. Overall, the risk of frostbite is less than 5% when the ambient temperature is above −15°C, but increased safety surveillance is warranted when the WCTI decreases below −27°C, as frostbite can occur in 30 min or less.[14]

Table 1 Key characteristics of Olympic sports influencing risk of cold injury to participants

Sport	Metabolic rate of competitors (W), (METS)	Event duration (min)	Airspeed (km/h)
Alpine skiing, freestyle skiing, ski jumping, snowboarding	700–1000 (7–11)	1.5–3	22–100
Sledding (Bobsled, Luge, Skeleton)	600 (6–7)	1–3	24–64
Nordic skiing, Biathalon, Nordic combined	1250–1800 (13–18)	24–125	22–27
10-K open water swimming	870 (9–10)	120	–

km/h, kilometres per hour; METS, metabolic equivalent; W, Watts.

Hypothermia prevention

In contrast to freezing injury, hypothermia can occur at any ambient temperature that enables body heat losses to exceed metabolic rate. Even exposures to temperatures well above freezing can lead to hypothermia if metabolic rate is low, and wet/windy conditions facilitate cooling relative to still, dry-air conditions. Heat-loss prediction models[19] suggest that an average-size person whose clothes are wet can maintain core temperature above 35°C for at least 7 h if exercise is sufficiently intense enough to sustain metabolic rates of 600 W or higher. Empirical data confirm that prediction, showing that core temperature remained normal or above normal during exercise at intensities above 60% VO_{2max} (600–700 W) in 4°C, 20 km/h wind speed conditions.[20] During all 'at-risk' Olympic events, metabolic rate is 600 W or higher, and exposure durations of most are less than 3 min, so there is little likelihood of hypothermia during a competition. While some Nordic skiing events do last as long as 2 h, metabolic rates during these events are higher, further limiting the likelihood of hypothermia, even if skin and clothing become wet. However, during experimental exposures to 4°C, 20 km/h wind speed, core temperature was observed to decline when exercise intensity was low (eg, 35% VO_{2max}) and clothing was wet.[6 11 20] Therefore, the risk of hypothermia increases during precompetition and postcompetition periods if competitors are not provided access to shelter or additional protective clothing. Additionally, particularly during training, athletes who unexpectedly stop exercising (eg, injury) and/or become wet before reaching shelter are at risk of hypothermia.

The greatest risk of hypothermia during Olympic events may not be during the Winter Games. Participants in long-distance, open-water swimming events might be at the greatest risk of hypothermia of all Olympic athletes. Recognising this hazard, the international swimming association does not permit competition in water temperatures below 16°C, measured 1.4 m below water surface.[21] Modelling predictions[22 23] suggest that core temperature of a male athlete having typical body composition of Olympic swimmers and swimming at a sustained pace of $1.4\ m\,s^{-1}$ in 16°C open water will fall to ~35.7°C. Core temperature for a female Olympic swimmer having a typical body composition and swimming at $1.3\ m\,s^{-1}$ in 16°C water is actually predicted to increase by ~0.5°C, and is only predicted to decrease by 0.5°C in 12°C water temperature. However, if the pace maintained by these athletes slows down as they fatigue, the swimmer is likely to reach clinical levels of hypothermia.

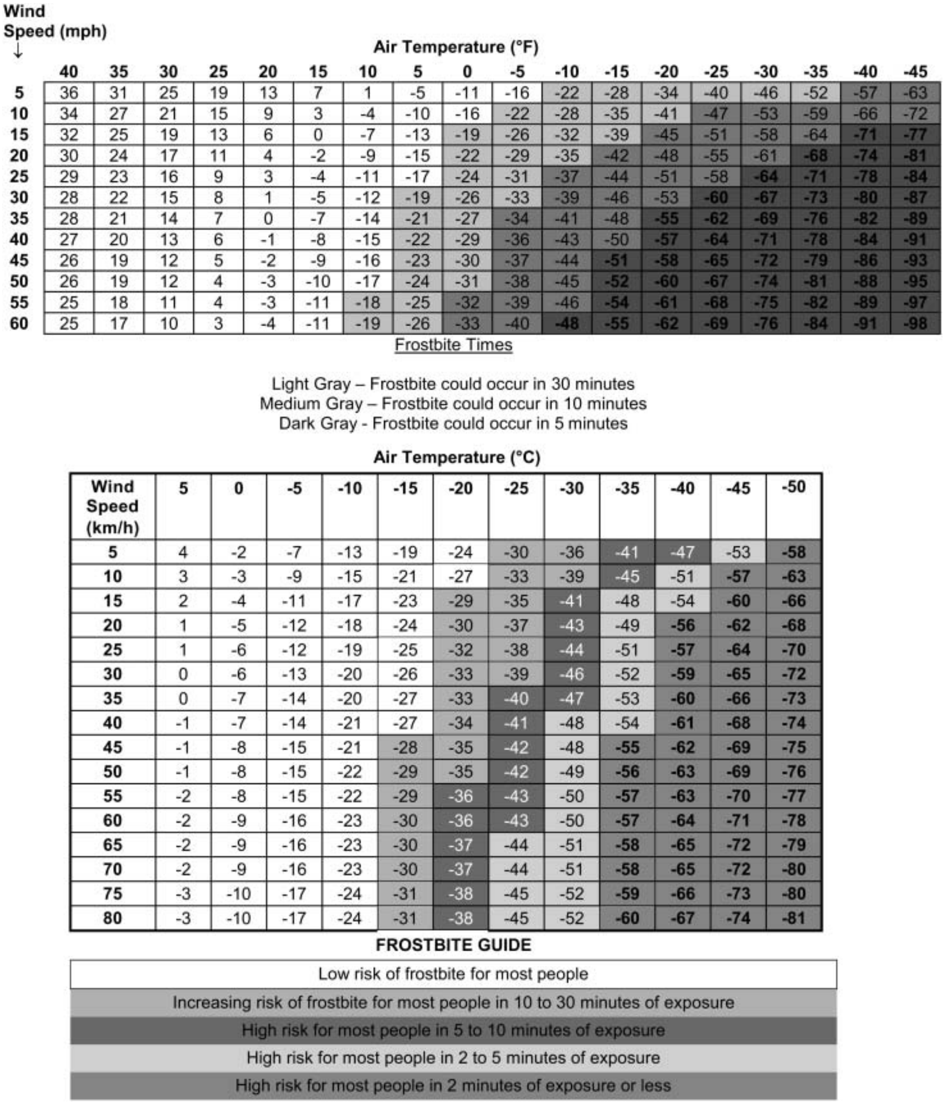

Figure 2 Wind Chill Temperature Index in Fahrenheit and Celsius. Frostbite times are for exposed facial skin. Top chart is from the US National Weather Service; bottom chart is from the Meteorological Society of Canada/ Environment Canada.

Wind Speed (mph) ↓

Air Temperature (°F)

	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times

Light Gray – Frostbite could occur in 30 minutes
Medium Gray – Frostbite could occur in 10 minutes
Dark Gray - Frostbite could occur in 5 minutes

Air Temperature (°C)

Wind Speed (km/h)	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
20	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
25	1	-6	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70
30	0	-6	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
35	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
40	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
45	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
50	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
55	-2	-8	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
60	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
65	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
70	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
75	-3	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
80	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

FROSTBITE GUIDE

Low risk of frostbite for most people
Increasing risk of frostbite for most people in 10 to 30 minutes of exposure
High risk for most people in 5 to 10 minutes of exposure
High risk for most people in 2 to 5 minutes of exposure
High risk for most people in 2 minutes of exposure or less

SUMMARY AND CONCLUSION

Cold injury is a concern during athletic training and competition. Our analysis indicates that the risk of cold injuries during the Winter Olympics is probably quite small due to the absence of extreme (–20°C), the high metabolic rates athletes produce during their events (>600 W), and the duration of many of the events (~3 min). Hypothermia is more likely to occur during the 10 K open-water swim during the Summer Olympics, if water temperatures approach 16°C. The risk of cold injuries during training and non-Olympic competitions could be higher than during Olympic competition. Employment of formal risk management processes such as those recommended by the American College of Sports Medicine[14] can effectively mitigate those risks during competition and training.

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