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Preparing for snow-sport events at the Paralympic Games in Beijing in 2022: recommendations and remaining questions

K Fagher ,[1,2] J K Baumgart,[3] G S Solli,[3,4] H C Holmberg,[5,6] J Lexell,[1,7] Ø Sandbakk[3]

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[1]Department of Health Sciences, Lund University, Lund, Sweden
[2]The Swedish Paralympic Committee, Stockholm, Sweden
[3]Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology, Trondheim, Norway
[4]Department of Sports Science and Physical Education, Nord University, Bodo, Norway
[5]Department of Health Sciences, Luleå University of Technology, Luleå, Sweden
[6]Department of Physiology and Pharmacology, Biomedicum C5, Karolinska Institutet, Stockholm, Sweden
[7]The Medical Committee, The International Paralympic Committee, Bonn, Germany

Correspondence to
Dr K Fagher;
kristina.fagher@med.lu.se

ABSTRACT

During the 2022 Winter Paralympic Games in Beijing, the Para snow-sport events will be held at high altitudes and in possibly cold conditions while also requiring adjustment to several time zones. Furthermore, the ongoing COVID-19 pandemic may lead to suboptimal preparations. Another concern is the high rate of injuries that have been reported in the Para alpine and snowboard events. In addition to these challenges, Para athletes various impairments may affect both sports-specific demands and athlete health. However, the group of Para snow-sport athletes is an understudied population. Accordingly, this perspective paper summarises current knowledge to consider when preparing for the Paralympic Games in Beijing and point out important unanswered questions. We here focus specifically on how sport-specific demands and impairment-related considerations are influenced by altitude acclimatisation, cold conditions, travel fatigue and jetlag, complications due to the COVID-19 pandemic, and injury prevention and sports safety considerations. As Para athletes with spinal cord injury, limb deficiency, cerebral palsy and visual impairment account for the majority of the Para snow-sport athletes, the focus is mainly on these impairment groups. In brief, we highlight the extra caution required to ensure athlete health, performance and sports safety among Para athletes participating in the snow-sport events in the 2022 Beijing Paralympic Games. Although there is an urgent need for more high-quality research focusing on Para winter athletes, we hope these non-consensus recommendations will help prepare for the 2022 Beijing Paralympic Winter Games.

Key messages

What is already known

- The Para snow-sport event in the 2022 Winter Paralympic Games in Beijing will be held at high altitude, and in possibly cold conditions while also requiring adjustment to several time zones.
- In addition, Para athletes may face challenges related to the ongoing COVID-19 pandemic and the risk of other illnesses and injuries.
- Winter sports research is a growing field within the Olympic population, but there are few studies that have assessed performance and athlete health in winter Para sports.

What are the new findings

- Para athletes may experience impairment-related performance limitations and health issues related to the cardiorespiratory, metabolic and thermoregulatory systems.
- The Omicron VoC is considerably more contagious than the previous versions of the SARS-CoV-2 virus that was dominant during the Summer Paralympic Games, and the consequences of Omicron infection before and during the Paralympics are still disquieting.
- In the future, more sophisticated experiments and observational studies focusing specifically on Para winter sports are warranted.

INTRODUCTION

The 2022 Paralympic Winter Games in Beijing will be the first Games organised at high altitude (~1700 m), with an expected number of around 750 athletes competing in two indoor (Para ice hockey, wheelchair curling) and four outdoor winter sports (Para snowboard, Para alpine skiing and Para Nordic skiing, which includesPara biathlon and Para cross-country (XC) skiing).[1] The combination of high altitude with cold and highly variable temperatures and dry air creates particularly challenging conditions for athletes competing in outdoor snow sports, which together account for 93% of the medals awarded during the Beijing Paralympic Winter Games. In addition, para athletes are more susceptible to injuries than Olympic athletes both during training and during competitions directly at Paralympic Games, with the highest injury rates in Para alpine and snowboard events during the previous Paralympic Winter Games.[2–4] Moreover, Para athletes from Europe and North and South America have to adjust to the new time zone after travelling long distances. Lastly, the ongoing COVID-19 pandemic requires modification of training programmes travelling itinerates and may reduce the size of the athletes' support team. Sudden changes in the competition programme may also occur right before or even during the Paralympic Winter Games themselves. Compared with Olympic winter sports athletes, the challenges related to high altitude, cold weather, risk of injury, travelling across time zones and the COVID-19 pandemic may be exacerbated in Para athletes due to impairment-related factors.

As researchers within the Paralympic field, this motivated us to present recommendations when preparing for the Paralympic Games in Beijing, focusing on outdoor snow sports and posing questions that future research should answer. We here put special emphasis on Para athletes with spinal cord injury (SCI), limb deficiency (ie, amputation and dysmelia), cerebral palsy (CP) and visual impairment (VI), who together account for the majority of the Paralympic winter sports athletes.

SPORT-SPECIFIC DEMANDS

Para XC skiing and biathlon are endurance sports, in which athletes compete in race courses consisting of undulating terrain with uphill, flat and downhill segments. In Para XC skiers, it has been shown that the varying terrain leads to substantial variation in speed, which is regulated by the selection of pacing strategies, subtechniques, and related kinematic patterns.[5 6] While this has not yet been investigated for Para XC skiers and biathletes, the aerobic energy contribution during races is expected to be similar as in their able-bodied counterparts, and in the range of 80%–95%.[7–10] Therefore, performance is mainly determined by a high peak oxygen uptake ($\dot{V}O_{2peak}$), the performance maximum rate of oxygen ($\dot{V}O_{2max}$) and exercise efficiency.[9 11] In addition, Para biathletes need to pace their speed to optimise shooting performance while at the same time balancing this with high endurance performance demands.

Para alpine skiing and snowboard are technical sports, which place high demands on the athlete's technical skill, balance and motor control.[12 13] In addition, these sports challenge the athlete's strength, power, aerobic and anaerobic capacity.[12 13] The demands of Para snowboarding athletes and Para alpine skiers that compete in the categories for standing or visually impaired athletes are similar to their able-bodied counterparts.[14] For Para alpine skiers that compete in the sitting classes, it appears that the endurance and strength demands are lower, and the athlete-equipment interaction, as well as the interaction of the equipment with the external forces and the snow surface, might be even more crucial.[14]

CLASSIFICATION

Para athletes in the snow-sports events compete in different categories and classes to ensure fair competitions, depending on the functional limitations caused by their specific impairment (figure 1). The classification systems in Para XC skiing, Para biathlon and Para alpine skiing are similar, and athletes compete in three different categories: (1) physically impaired sitting skiers, (2) physically impaired standing skiers and (3) visually impaired standing skiers. Within each of these categories, athletes are further divided into several classes. Due to low numbers of athletes within classes, all classes in one category compete against each other, and a class-specific time factor is used to adjust the race time. In Para snowboard, there are two classes for athletes with lower-limb impairments and one for athletes with upper-limb impairments.[15]

IMPAIRMENT-RELATED CONSIDERATIONS

While athletes with different impairments but similar magnitude of functional limitations may compete in the same class, there are limitations in the above-described sport-specific demands, which are impairment-specific. These are summarised below for the most common impairment types; SCI, CP, limb deficiency and VI. While some athletes have unaffected cardiorespiratory, metabolic and thermoregulatory responses (eg, athletes with VIs), others exhibit markedly reduced responses (eg, athletes with thoracic and cervical SCI). In this context, it should be noted that the level of impairment of most of the Para winter sports athletes within each of these impairment types is rather mild.

Spinal cord injury

In endurance athletes with an SCI $\dot{V}O_{2peak}$ is 15%–60% lower than their able-bodied counterparts due to lower active muscle mass when exercising with the upper body only and due to cardiorespiratory limitations.[16] Active muscle mass and cardiorespiratory function are increasingly affected by higher levels of the SCI. More specifically, athletes with a motor and sensory complete SCI at the Th6 level or above lack sympathetic innervation of the lower extremities and organs.[17] This leads to a lack of vasoconstriction, which reduces blood redistribution to the active musculature. Furthermore, in athletes with tetraplegia, sympathetic innervation of the heart is affected, which may cause lower blood pressure and a lack of increase in heart rate during training and competitions.[18] In line with the lower $\dot{V}O_{2peak}$, the $\dot{V}O_2$ at the anaerobic threshold is also lower in athletes with SCI due to exercising with a lower active muscle mass of the upper body. Accordingly, exercise efficiency was lower during upper- compared with lower-body exercise.[19 20] However, exercise efficiency during upper-body exercise was not different in athletes with SCI compared with their able-bodied counterparts, that is, athletes with an SCI produced lower power output but also used proportionally less $\dot{V}O_2$.[21] While higher blood lactate concentration (BLa) values were found at a given speed or perceived exertion during upper- compared with lower-body exercise,[22] BLa clearance after exercise during upper-body exercise was similar for athletes with and without an SCI.[23] Sport-specific demands in athletes with SCI may also be negatively affected by overuse injuries to the shoulder, osteoporosis, pressure ulcers, impaired

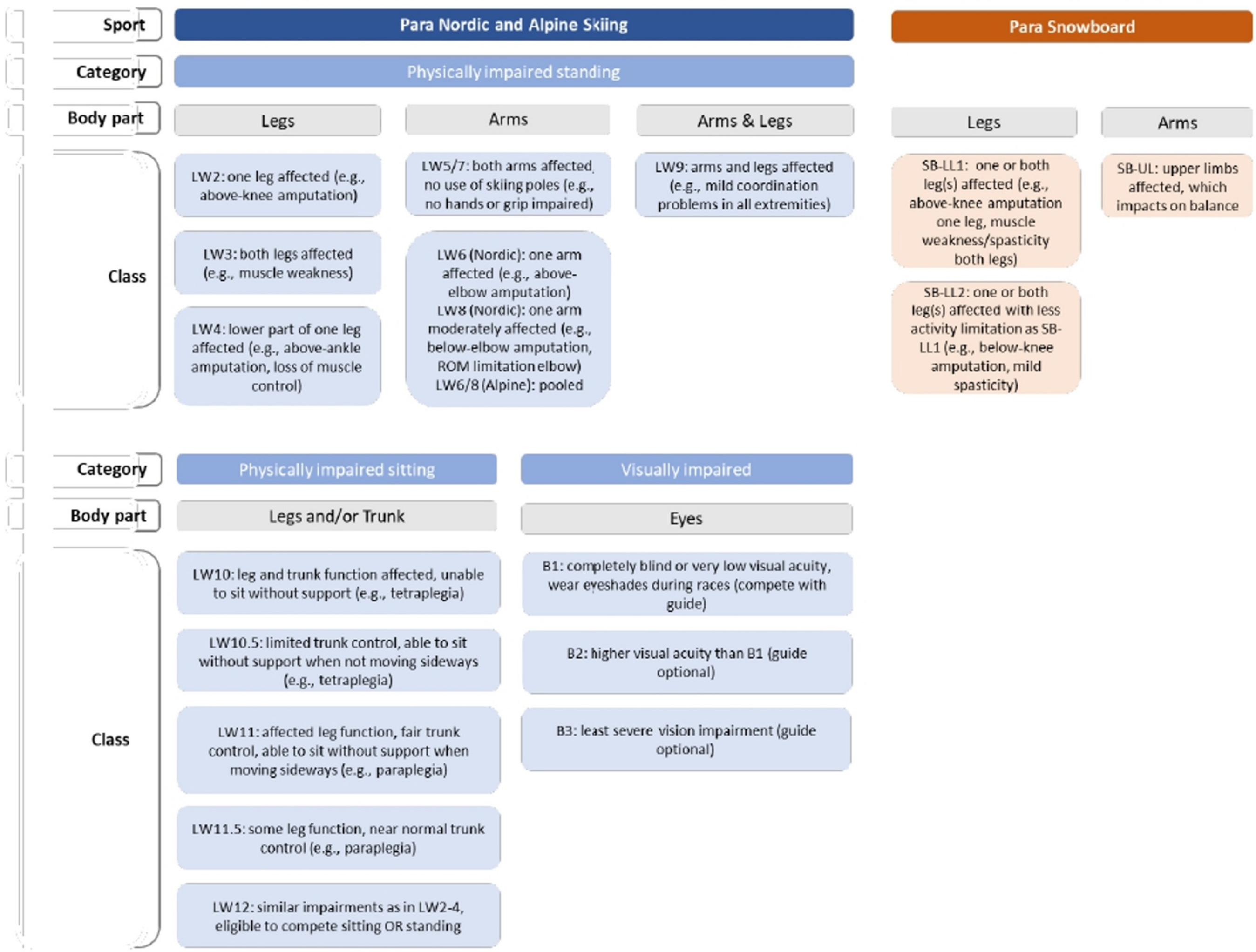

Figure 1 Categories and classes in Para Nordic Skiing (ie, cross-country skiing and biathlon), Para Alpine Skiing and Para Snowboard.

thermoregulation and neuropathic pain, factors that are presented more specifically in table 1.

Limb deficiency

Little research is available on individuals and athletes with upper-limb amputations, and this section, therefore, focuses on what is known for those with lower-limb amputations, which by extension should apply to those with dysmelia of the lower limb. Untrained individuals with a below-the-knee amputation were found to have similar $\dot{V}O_{2peak}$ as compared with non-disabled individuals.[24] At the same time, $\dot{V}O_{2peak}$ was 35%–40% lower in individuals with an above-the-knee amputation due to lower active muscle mass and limitations in attaining high walking/running speed.[25 26] While this has not yet been investigated, we expect reduced differences in $\dot{V}O_{2peak}$ between Para athletes with an above-the-knee amputation and non-disabled athletes. Furthermore, energy consumption at a given walking/running speed was reported to be higher in untrained individuals with below-the-knee and above-the-knee amputations compared with non-disabled individuals due to compensatory muscle activity.[27] However, similar exercise efficiency was found in athletes with unilateral and bilateral amputations,[28] indicating that high-level training can compensate for initial reductions in this parameter. Sport-specific demands in athletes with limb deficiency may also be negatively affected by stump-related issues and overuse injuries (table 1).

Cerebral palsy

Compared with able-bodied controls, endurance-trained adults with CP had 0.3%–21% lower peak oxygen uptake ($\dot{V}O_{2peak}$).[29] This difference is considerably lower than other studies found when comparing untrained age-matched controls with and without CP and highlights the positive effects of exercise.[30] In addition, exercise efficiency is reduced in athletes with CP arguably due to muscle spasticity, decreased range of motion and pain.[31 32] Anecdotally, higher BLa values at a given speed/power output have been reported in athletes with CP compared with able-bodied counterparts, which is likely related to the muscle spasticity negatively influencing the diffusion of blood from active muscle mass to venous blood. Furthermore, strength is reduced in athletes with CP

Table 1 Non-exhaustive summary of current knowledge of impairment-related considerations, and corresponding applied practical recommendations for challenges associated with elevated altitude, cold temperatures, travel and jetlag and athlete health and safety at the 2022 Beijing Paralympic Games

Challenge	Impairment	Specific impairment-related considerations	Applied practical impairment-related considerations during the paralympic games
Altitude	Spinal cord injury (SCI)	▶ The central nervous system and respiratory system are affected in athletes with high-level paraplegia or tetraplegia, which may diminish the ability to adjust to altered barometric pressure (Theisen[71]). ▶ Data have shown that athletes with neurological impairment report a high rate of acute mountain sickness (Kamaraj *et al*[72])	▶ Plan for prolonging the period of altitude acclimatisation. ▶ Careful monitoring of acute mountain sickness.
	Cerebral palsy	▶ Physical performance may decline, and fatigue increase especially in athletes with more severe cerebral palsy (Dodge[73]). ▶ Cognitive impact on pacing awareness can be particularly challenging when competing at high altitudes (Runciman *et al*[74]).	▶ Careful monitoring of load during training, competitions and daily life, increased recovery may be needed.
	Limb deficiency	–	–
	Visual impairment	–	–
Cold	SCI	▶ The magnitude of thermoregulatory limitations is proportional to the level of injury ▶ Athletes are predisposed to hypothermia due to (Handrakis *et al*[75]): – Disruption of the autonomic nervous system and sympathetically induced vasoconstriction absent or delayed. – Reduced ability to generate body heat by shivering due to lack of motor control of skeletal muscles below the level of injury. ▶ Increased risk for frostbites and pressure ulcers due to reduced skin response and vasomotor control below the lesion level (Theisen[71]).	▶ Careful monitoring of hypothermia. ▶ Special attention must be given to wearing appropriate clothing and minimising exposure to cold temperatures. ▶ Signs of hypothermia in athletes with SCI should be dealt with at an earlier stage than in the case of able-bodied athletes. ▶ Careful monitoring of skin temperature and screening for frostbites and pressure ulcers.
	Cerebral palsy	▶ Greater metabolic heat at a given workload may be present, heat may potentially be lost more rapidly (Griggs *et al*[76]). ▶ Botox injections may possibly reduce skin response ▶ Potential reduction in already impaired venous return may be attenuated due to even higher muscular tone in response to the cold (higher relative intensity of exercise due to higher heart rate to compensate for lower stroke rate) (Griggs *et al*[76]). ▶ Cognitive impact on pacing awareness is particularly challenging when competing in cold temperatures (Cameron *et al*[77]).	▶ Careful monitoring of hypothermia. ▶ Special attention must be given to wearing appropriate clothing and minimising exposure to cold temperatures.
	Limb deficiency	▶ With high-level amputations, skeletal muscle mass may be reduced and heat may be lost more rapidly. ▶ Greater metabolic heat production at given workload due to movement asymmetries, heat may potentially be lost more rapidly. ▶ Reduced surface area for temperature regulation due to (Griggs *et al*[76]) – Loss of limb. – Residual limb partially covered by prosthesis. – Possible skin grafts. ▶ Impaired skin response at the athleteprosthetic-interface may potentially lead to increased risk for blisters/sores.	▶ Careful monitoring of hypothermia. ▶ Special attention must be given to wearing appropriate clothing and minimising exposure to cold temperatures.
	Visual impairment	–	–
Travel and jetlag (Vanlandewijck and Thompson[78])	SCI	▶ Potentially increased risk for respiratory tract infections during long flights particularly in athletes with tetraplegia who often have impaired respiratory function. ▶ Increased risk for pressure sores during long flights. ▶ Increased risk for deep venous thrombosis during long flights. ▶ Potentially increased risk for urinary tract infections during long flights.	▶ Be extra conscious to minimise the high risk of infection (see table 2). ▶ Plan the food and hydration intake during the travel both in relation to timing, hygiene and type of food that is optimal during the travel. ▶ During long flights, choose comfortable seating, including customised seat cushions, preferably in business class. ▶ Screen for pressure ulcers. ▶ Use compression socks designed to avoid deep venous thrombosis. ▶ Apply good routines for using bladder catheter on flights.

Continued

Table 1 Continued

Challenge	Impairment	Specific impairment-related considerations	Applied practical impairment-related considerations during the paralympic games
	Cerebral palsy	▶ Increased fatigue due to cognitive overload during travelling. ▶ Increased spasticity due to stress during travelling.	▶ Be particularly aware of the additional load of the travel and its possible impact of the different impairments and make adjustment according to this. ▶ Ensure high-quality sleep and enough recovery before departure and after arrival. ▶ Reduce training load after arrival.
	Limb deficiency	▶ Increased risk for ulcers and blisters due to swelling of limbs during long flights.	▶ Prostheses should not be worn while travelling.
	Visual impairment	▶ Disturbance in circadian rhythm is common in athletes with severe visual impairment (Lockley *et al*[79]). Adjusting to a new time zone due to not being able to make use of light as a cue may be challenging. ▶ General fatigue is common in this athlete population	▶ Plan for prolonging the period of adjustment to the new time zone. ▶ Prioritise rest.
Athlete health and sports safety (Vanlandewiijck and Thompson[78], Fagher[80])	SCI	▶ Overuse injuries and pain of the shoulder joint(s) are common among athletes using the upper body for mobility in daily life by means of a wheelchair, and during competitions in a XC or Alpine sit-ski. ▶ Osteoporosis is common in this population. ▶ Pressure ulcers may appear due to new clothes and long competition days.	▶ Important to optimise load and recovery. ▶ Powered wheelchair to reduce load during daily life in periods with high training or competition load. ▶ Screen for fractures and stress fractures following a collision. ▶ Monitor for ulcers carefully each day.
	Cerebral palsy	▶ Spasticity may be aggravated during the games period. ▶ Epilepsy may be aggravated during the games period due to stressful situations. ▶ Orthopaedic defects may cause pain.	▶ Apply physical therapy, medication/injections and braces. ▶ Minimise the risk for seizure. ▶ Important to optimise load and recovery in order to avoid pain, injury and spasticity.
	Limb deficiency	▶ Musculoskeletal pain and stress may increase due to compensatory sport movements, and more walking in the Paralympic village.	▶ Important to optimise load and recovery in order to ovoid stump and overuse injuries.
	Visual impairment	▶ Collisions, falls, acute injuries and concussions are common injuries among athletes with visual impairment especially in unfamiliar environments.	▶ Ensure optimal guiding and support.

We here focus on Paralympic snow-sport athletes with an SCI, cerebral palsy, limb deficiency or visual impairment.

due to decreased central input caused by brain damage, coactivation of antagonists muscles, increased type 1 muscle fibres, increased intramuscular fat and muscle atrophy.[33 34]

Visual impairment

Compared with highly trained non-disabled individuals, partially or completely blind athletes showed around 15% lower $\dot{V}O_{2peak}$,[35 36] and lower exercise efficiency.[36] This is most likely entirely related to lower locomotor efficiency and dynamic balance,[37 38] since most VI athletes do not have cardiorespiratory limitations. For partially sighted athletes, the differences in $\dot{V}O_{2peak}$ and exercise efficiency compared with their able-bodied counterparts are expected to be lower than in fully blind athletes. Furthermore, athletes with VI may be negatively affected by fatigue, circadian rhythm disturbances and acute sports injuries (table 1).

ALTITUDE ACCLIMATISATION

Effect of altitude on endurance performance

At approximately 1700 m, the partial pressures of nitrogen and oxygen are reduced, and only 79% and 21%, respectively, of the amount at sea level, are available at this altitude.[39] Bad weather conditions might further reduce these partial pressures. The effects of altitude can be divided into (1) those affecting the interaction of the athletes and their equipment with the environment (ie, slightly less gravity and air drag) and (2) those affecting the human physiology due to less availability of oxygen. While the former effects are likely largest yet small in Para alpine skiing and Para snowboard, the effect of altitude on aerobic endurance is more pronounced and performance is particularly impacted in the endurance events. In the following, we will focus mainly on the effect of altitude on sport-specific demands of the (Para) endurance snow-sports.

In non-disabled endurance athletes, the saturation of blood with oxygen during maximal exercise declines by 5.5%, and $\dot{V}O_{2max}$ by 6.3% (4.5%–7.5%) per 1000 m elevation in altitude.[40] These decrements in maximal endurance capacity are highly individual, perhaps due to individual differences in hypoxic ventilatory responses or kinetics of oxygen delivery.[41] While this has not yet been investigated in Para athletes, we expect similar or larger performance decrements depending on the type and level of impairment, speculatively with even larger inter-individual variations due to the large impairment-related heterogeneity of Para athletes. Furthermore, increased ventilation and heart rate were found in non-disabled athletes when training and competing at elevated altitude, with similar or larger increases expected in Para athletes depending on the type and level of impairment. Accordingly, altitude-related increase in ventilation and heart rate may be particularly challenging for Para biathletes in connecting to shooting performance.[11]

Non-disabled and Para athletes alike often also experience that the duration and quality of their sleep are compromised at higher altitudes,[42] possibly due to respiratory events such as periodic breathing.[43] The latter may be particularly concerning for Para athletes as it has been shown that this population already is predisposed to a greater risk of poor sleep due to impairment-related comorbidities.[44]

Acclimatisation to altitude

The long-term physiological adaptations to altitude include a rise in the level of erythropoietin and subsequent increases in the production of red blood cells (erythrocytes) and total mass of haemoglobin.[39 41] These changes were found to normally require at least 2–3 weeks of altitude exposure in non-disabled athletes.[45 46] However, we will focus here solely on the influence of acclimatisation low-to-moderately elevated altitudes (eg,~1200–1800 m) on performance. Such ‘short-term’ performance improvements due to 10–14 days of acclimatisation may be achieved by more rapid and deeper breathing (referred to as hypoxic ventilatory response), both when resting and exercising.[39] The accompanying increase in blood pH (respiratory alkalosis) limits this response but can be eliminated within 4–7 days through renal bicarbonate secretion, allowing subsequent chemoreceptor-mediated respiratory enhancement.[39] However, the mechanisms related to possible performance improvements from acclimatisation are relatively unexplored.

In this context, when preparing for the Beijing Paralympic Games, various ‘live low-train high’ strategies[47] rather than living and training at elevated altitude might be considered,[39] especially with the travel restrictions designed to prevent the spread of COVID-19. This might involve intermittent or chronic hypoxia with or without accompanying exercise (eg, treadmill roller-skiing). Although no controlled comparisons have been made even in non-disabled athletes, there are some indications that living and training where the competitions will be held promotes more optimal acclimatisation,[48] which is likely also the case for Para athletes.

In addition to altitude acclimatisation, athletes who have trained and competed at relevant altitudes before the Beijing Paralympics are likely to optimise warm-up procedures, pacing strategies, techniques and tactics much more effectively. For example, less oxygen availability enhances the risk for greater oxygen debt early in the competition, so pacing becomes more important. In this context, technological developments such as highly accurate global navigation satellite systems allow detailed analyses of training and competition that should help establish the relationship between the perceived and actual intensity of exercise.[6]

While table 2 summarises recommendations for optimal altitude acclimatisation in preparation for both the Beijing Olympic and Paralympic Games,[49] table 1 includes impairment-specific considerations and applied practical recommendations to be aware when Para athletes with SCI, CP, limb deficiency and VI acclimatise in advance to competitions at low-to-moderate altitudes.

Table 2 Recommendations for optimising preparations of Olympic and Paralympic athletes in snow-sport events to challenges associated with elevated altitude, cold temperatures, travel and jetlag at the 2022 Beijing Olympic and Paralympic Games based on Sandbakk *et al*[49] with minor modifications

Challenge	General applied practical recommendations—long term	General applied practical recommendations—short term
Altitude	▶ In advance, train for at least 60 days and participate in several competitions at this elevation or higher. ▶ Individualise training, recovery, pacing, technique and nutrition appropriately.	▶ As close in time prior to the Games as possible, train for 0–14 days at the altitude of competition, either at the actual venue for the Games or in Europe or Asia (which will require later adjustment of the circadian rhythm). ▶ Alternatively, live and train for 14–21 days above 2000 m, followed by 7–10 days at ~1700 m. For maximal erythropoiesis, blood levels of ferritin should be >30 ng/mL prior to exposure to altitude and oral supplementation with iron (~100–200 mg daily) individualised during this exposure. ▶ Acclimatisation and performance at elevated altitudes with maintenance of good health is dependent on appropriate nutrition and hydration, and good sleep hygiene and routines
Cold	▶ Adapt individualised warm-up procedures, pacing strategies and clothing to different temperatures and potentially changing environmental conditions in an appropriate manner.	▶ Wear clothing that ensures maintenance of core body temperature. ▶ Develop a strategy for maintaining body temperature effectively during the interval between warm-up and competition. ▶ Adapt individualised warm-up and pacing to prevailing environmental conditions, especially at the beginning of a race. ▶ Preparation must be made for treatment of asthmatic symptoms when respiration is rapid at cold temperatures.
Travel and jetlag	▶ Exposure yourself to (day)light in a manner that optimises adjusting your circadian rhythm and consider dietary supplementation with 2–5 mg melatonin, if needed. ▶ Schedule meals and social activities on the basis of the local time. ▶ Short (20–30 min) naps can promote recovery and alertness. ▶ During the initial few days, total training load should be reduced and intensive high-intensity training avoided.	▶ Arrive at least 1 day earlier for each hour by which your time zone differs from that in Beijing. ▶ Before departure, shift your sleep and eating schedule by 0.5–1 hour daily for three or 4 days towards the anticipated schedule in Beijing. ▶ Travelling east during the afternoon and night increases the chances of sleeping well during the flight. ▶ Avoid dehydration by drinking appropriate volumes of fluids free from alcohol or caffeine. ▶ To minimise the high risk of infection associated with air travel, try to avoid crowds and use a face mask when it is difficult to keep distance, wash your hands frequently.
Athlete health and sport safety	▶ Monitor injuries and illnesses in detail, both during training and the Olympic/Paralympic Games themselves to identify the extent of the problem. ▶ Work proactively with injury and disease prevention, athlete health, and education within the Olympic/Paralympic movement and the National Olympic/Paralympic Committees.	▶ Allow athletes to train on and test the actual competition courses in advance. ▶ Do not hesitate to cancel or postpone competitions if the weather is too bad or other conditions poor. ▶ Adhere to the COVID-19 regulations put in place specifically for the Paralympic Games.

In addition, we here provide general recommendations for athlete health and sport safety at the 2022 Beijing Olympic and Paralympic Games.

PERFORMING IN THE COLD

The ambient temperatures during the Beijing Paralympics may vary from −15° to plus degrees, with rapid changes from 1 day to another. Depending on the type and level of impairment, thermoregulation may be more challenging in Para athletes when adapting to cold temperatures of −5°C to −15°C or lower. In cold temperatures, especially in the presence of wind, the core body temperature rises, while skin temperature falls due to cooling the superficial musculature.[50] Such cooling causes muscles to produce less aerobic energy and fatigue more rapidly and attenuate nerve and muscle excitability and nerve conduction,[51] all of which may lower overall power production and may especially affect Para athletes due to the nature of various impairments (table 1).

Although endurance performance diminishes as the temperature falls, some studies on non-disabled athletes have reported no effects of ambient temperature on $\dot{V}O_{2max}$.[52 53] In contrast, other studies have observed reductions in $\dot{V}O_{2max}$ in cold temperatures.[53–56] While relatively little is known concerning the effects of cold on endurance performance and related physiological mechanisms in Para snow-sport athletes, the negative effects of the cold on endurance performance are likely similar or enhanced depending on the type and level of the impairment. We describe impairment-specific considerations based on deductions from how the different impairments theoretically should be impacted by cold temperatures, in addition to applied recommendations that are experience-based on practices of many of the Para snow-sport teams (tables 1 and 2). Moreover, at altitudes of ~1700 m or higher, the low humidity combined with cold air, as is often the case at the competition arenas used during the Beijing Olympic and Paralympic Games, challenges respiration. This is especially the case for Olympic and Paralympic athletes with asthma, which will require appropriate medication to at least in part compensate for asthma-related respiratory limitations.

TRAVEL FATIGUE AND JET LAG

Para athletes from Europe and North and South America will have to fly for 10–15 hours across ~8 time zones to reach Beijing, experiencing travel fatigue and jet lag. Individuals react differently to the desynchronisation of established biological rhythms from the local time. The most common symptoms in non-disabled athletes are poor night-time sleep, tiredness during the day, loss of appetite, gastrointestinal disturbances and impaired mental/or physical performance.[57–60] Several studies have also reported reduced performance in relation to travel fatigue and jet lag in able-bodied athletes.[57 58] Furthermore, in able-bodied, it is well documented that international air travel is the single most important risk factor for upper respiratory tract and gastrointestinal infections.[61 62] Other travel risk factors include inadequate intake of nutrients and dehydration.[61] While there is a lack of studies investigating these factors in Para athletes, they are likely exacerbated for many Para athletes due to the nature of their impairment, and accordingly, impairment-specific travel strategies and optimal recovery after travelling become even more crucial.

In non-disabled athletes, it is well documented that sleep deprivation leads to more errors, impaired decision-making, slower attainment of maximal power, greater fatigue and less ability to exercise maximally, while also increasing the risk of illness.[63–65] Since sleep deprivation appears to be common among Para athletes,[4 44] it may be of particular importance to ensure high sleep quantity and quality for several weeks or months before travelling to Beijing.

To reduce the impact of travel fatigue and jet lag on performance, we recommend that Para athletes, coaches and support staff consider actions before, under and after travel. Actions recommended for non-disabled athletes are discussed in more detail in a previously published study,[49] and a summary is provided in table 2. Furthermore, we here provide impairment-specific considerations and corresponding applied practical recommendations in table 1.

COMPLICATIONS DUE TO THE COVID-19 PANDEMIC

The innumerable changes due to the global COVID-19 pandemic include limitations on athletic training and competition, and anecdotal evidence suggests that Para athletes have been even more affected than their able-bodied counterparts. While many Para athletes are at risk of suffering more severe consequences if they contract the coronavirus, infections rates during the Olympic and Paralympic Summer Games 2021 were very low (0.003%) and symptoms were not significantly increased for Para athletes.[66] A concern is, however, that the Omicron VoC is considerably more contagious than the previous versions of the SARS-CoV-2 virus. The global distribution of vaccines and growing natural immunity in populations reduce concerns about serious outcomes of infections. Nonetheless, the consequences of Omicron infection before the Paralympics are still disquieting. It is, therefore, important to have clear plans on how to manage symptomatic and asymptomatic athletes with positive COVID-19 test results at different points in time before and during the Paralympic Games. Moreover, it is crucial to establish psychological preparation of athletes that are not allowed to participate in the competitions due to a positive COVID-19 test even though they are asymptomatic. The strict isolation protocol for positive participants during the Paralympic Games can also expose some individuals to mental health issues, and it is important that each team has an established crisis plan that can support athletes and team officials that might be in quarantine in China for a longer period of time. Another important aspect is that it could be challenging for athletes with a visual or physical impairment to be isolated without their guide. At present, it is clear that this pandemic will affect the 2022 Beijing Paralympic Games, and in the meantime, athletes and coaches must make contingency plans for changing times zones, acclimatisation to altitude and competing in cold temperatures (tables 1 and 2).

INJURY PREVENTION AND SPORTS SAFETY

During the 2018 PyeongChang Paralympic Winter Games, 20% of all athletes sustained an injury,[3] compared with 12% of those participating in the corresponding Olympic Games.[67] The pattern during the 2014 Paralympic Winter Games in Sochi was similar, with corresponding injury rates of 24.5% vs 12%.[2 68] Most of the injuries during the Paralympic Games were acute, and not unexpectedly, Para alpine/snowboarding events demonstrated the highest rates. During the Sochi Paralympic Games, poor snow conditions due to warm weather may have contributed to injuries.[2] It is important when preparing the snow to consider that the Paralympic Games will be held almost 4 weeks after the Olympic Games.

During the PyeongChang Paralympic Winter Games, the incidence of injuries in the Para alpine events declined compared with the previous Paralympic Games, possibly due to preventive measures such as racecourse optimisation, allowing more training runs, and the possibility to change starting times.[3] However, the incidence of snowboarding injuries, primarily to the head/face/neck and lower leg, remained high. Para snowboarding is a relatively new sport, and inexperienced and faulty techniques could have contributed to these injuries, requiring appropriate education.[3] Yet, few studies describe the injury pattern specifically in Para Nordic skiing, but existing studies have shown that shoulder injuries are a concern.[3]

The various impairments which Para athletes have, along with the adapted equipment being used, often contribute to injuries.[4 69] Therefore, each athlete could benefit from a risk analysis designed to develop appropriate preventive measures before travelling to Beijing. Furthermore, each athlete should be monitored continuously through injury and illness surveillance adapted to Para athletes before and under competition.[3 4 70] Moreover, secondary and tertiary treatment of injuries should be planned. For example, in case of catastrophic injury, first responders must know how to release the athlete from special equipment such as sit-skis, sledges and wheelchairs. In addition, medical staff must know how to deal with serious trauma to athletes who already have some form of impairment, such as the bone mass, spinal cord, brain or cardiopulmonary system.

CONCLUSIONS AND FUTURE PERSPECTIVES

As described in detail above, the demands associated with Para winter sports events may be complicated by the elevated altitude in Beijing, potentially cold temperatures, challenges of travelling across multiple time zones, and potential limitations due to the COVID-19 pandemic. Here, we propose that extra caution is required for Para athletes since altitude acclimatisation may take a longer time, clothing is more crucial, and travel preparations, as well as jetlag considerations, are more extensive. Taking all these factors into consideration, we have attempted to formulate recommendations for athletes preparing for the Beijing 2022 Winter Paralympics (tables 1 and 2)

As already emphasised, many of these recommendations are based on limited scientific evidence for Para athletes, and we would like to clarify that this paper is based on non-consensus recommendations. In the future, more sophisticated experiments and observational studies focusing specifically on Para winter sports are warranted. These should employ new technology to simultaneously monitor performance indicators, physiological responses, injuries and environmental factors in connection with altitude training, exposure to cold temperatures and travel across time zones. Despite the limitations, we hope that our recommendations will be of value for athletes preparing to compete in the 2022 Beijing Paralympic Winter Games and beyond.

Twitter K Fagher @KristinaFagher

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ORCID iD

K Fagher http://orcid.org/0000-0002-9524-7553

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