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Training- and competition-related risk factors for respiratory tract and gastrointestinal infections in elite cross-country skiers

Ida S. Svendsen[1], Ian M. Taylor[1], Espen Tønnessen[2], Roald Bahr[2,3], Michael Gleeson[1]

1) School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, UK.
2) Department of Training, Norwegian Olympic and Paralympic Committee and Confederation of Sports, Oslo, Norway.
3) Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway.

Address for Correspondence:

Ida Siobhan Svendsen

School of Sport, Exercise and Health Sciences,

Loughborough University,

Leicestershire, UK.

LE11 3TU.

E-mail: i.s.svendsen@lboro.ac.uk

Telephone: +44 7794904859

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ABSTRACT

Aim: To determine risk factors for respiratory tract and gastrointestinal infections in elite cross-country skiers.

Methods: Self-reported training and inefction data for 37 elite cross-country skiers from 2007 to 2015 were analysed. Multilevel logistic regression equations were constructed with infection incidence and symptom duration as outcome variables, and sex, performance level, season, training phase, competition, air travel, altitude exposure, and training characteristics as independent variables.

Results: Data for 7,016 person-weeks were analysed, including 464 infection events and 110,959 hours of training. Athletes reported median (range): 3 (1-7) respiratory and/or gastrointestinal infections per year, with symptoms lasting 5 (1-24) days. During the winter, infections occurred more frequently (odds ratio 2.09, P<0.001) and lasted longer (b=0.043, P<0.001) compared to summer. Competition and air travel increased the risk of infection, with odds ratios of 2.93 (95% CI: 2.24-3.83) and 4.94 (95% CI: 3.74-6.53), respectively (P<0.001). Athletes with higher Training Monotony had lower risk of infection (odds ratio 0.87 (95% CI: 0.73-0.99), P<0.05). Other training variables were not associated with infection. Athletes who had won an Olympic/World Championship medal reported shorter duration of symptoms compared to less successful athletes (b=-0.019, P<0.05) resulting in significantly fewer annual illness days median (range): 14 (6-29) vs. 22 (8-43) days/year.

Conclusions: Air travel and competition are major risk factors for respiratory tract and gastrointestinal infections in this population. Athletes whose training programmes incorporate large fluctuations in training load appear to be more susceptible to infection. A robust immune system capable of recovering quickly from infection may be associated with success in elite cross-country skiing.

INTRODUCTION

Reaching an international level in any sport requires a high volume of training, and elite endurance athletes typically train between 500 h [1, 2] to in excess of 1,000 h per year [3-5], with elite cross-country skiers training ~800 h per year [6]. Cross-sectional studies indicate that individuals with high training loads experience a greater frequency of upper-respiratory illness [7]. Furthermore, longitudinal studies with athletes report an increased incidence of opportunistic infectious illness during periods of intense training or competition [8-10]. Malm [11] suggested that, although high training loads may suppress immunity, becoming a successful elite athlete requires an immune system capable of withstanding infections even during severe physiological and psychological stress. However, differences in illness susceptibility between the most successful athletes and their less successful counterparts, all of whom have similarly high training loads, has not been fully explored. It is possible that the ability to withstand and/or recover quickly from an illness, particularly during key training and competition periods, could be a predictor of success within an otherwise homogenous athlete group.

A recent study by Hellard et al. [10] investigated illness incidence amongst international swimmers over a four-year period, and found that illness rates were highest during the winter months and intensive training periods. However, it is not clear whether the same patterns for illness incidence are present for winter sports athletes, who compete during the winter months but typically undertake the highest training loads in the summer and autumn [6]. Furthermore, other than high training loads, elite athletes are exposed to a number of additional stressors, such as frequent international travel, altitude exposure and the psychological pressure of competition, which may also influence illness susceptibility [12-14].

The purpose of the current study was therefore: 1) to describe self-reported illness incidence for elite cross-country skiers across a number of competitive seasons, 2) to examine risk factors for illness, and 3) to determine whether there are differences in the number and/or duration of illness events between athletes that have won an Olympic/World Championship medal, and those athletes that have not. It was hypothesised that heavy training loads and competition would significantly increase the risk of illness, and that athletes who had medalled at world or Olympic level would report fewer illness events.

METHODS

Participants

Self-reported training and illness data for the period 01.05.2007 to 30.03.2015 were collected from 39 elite male (n=22) and female (n=17) cross-country skiers. Inclusion criteria were 1) selected to represent the Norwegian national senior or recruit team for cross-country skiing during the analysed time period, 2) over 18 years of age, and 3) had systematically and in detail recorded their day-to-day training from junior through to senior level. As of 30.03.2015, 16 of these athletes (9 males and 7 females) had won at least one individual senior Olympic or World Championship medal (totalling 73 individual Olympic and World Championship medals between them). These athletes were categorised as world-leading (WL), while those athletes that had not won an individual Olympic or World Championship medal were categorised as international level (IL). All athletes provided written, informed consent for their data to be included in the study, which was approved by the Loughborough University Ethical Review Committee and registered with the Norwegian Data Protection Authority.

Training and illness data

Athletes recorded their training in spreadsheet training diaries designed by the Norwegian Ski Federation or, since 2012, in the web-based version developed by the Norwegian Olympic Federation (www.olt-dagbok.net). The training recorded for each session included total training time for different training forms (endurance, strength/power, sprint, etc.) and intensity zone (Table 1). In addition, each session included “daily parametrics” and “comments” fields where athletes recorded additional information, including illness symptoms and whether training was discontinued or modified due to illness or injury, medication use, days of travel and days spent at altitude. In total, from 39 athletes, 143 person-years of data were collected, typically consisting of 3-4 years per athlete. Of these, two athletes (eight person-years) were excluded due to inadequate detail in the recording of either training or illness.

Table 1. The 5-zone intensity scale used by athletes to classify endurance training

Intensity Zone	Typical Blood Lactate (mmol/L)	Typical Heart Rate (% max)	Binary Model
5	> 5.8	> 94	
4	3.7-5.7	89-93	HIT
3	2.1-3.6	84-88	
2	1.3-2.0	74-83	LIT
1	< 1.2	54-73	

Reference values presented are derived from the average self-reported zone cut-offs of 29 elite XC-skiers [6].

Based on the definitions proposed by Matthews et al. [15] self-reported illness was categorized as “severe” when an athlete reported symptoms indicative of infectious illness *and* training was discontinued, or “moderate” when an athlete reported symptoms but continued to do some training. An illness event was defined as one or more symptoms on two or more consecutive days, or when the illness was categorized as “severe” on at least one day.

Symptoms had to be separated by a minimum of seven days in order to be categorised as two separate events. Where the athlete reported allergies, asthma, or gastrointestinal distress due to training/nutrition practices, these were not included. Only symptoms likely to be due to opportunistic infection were retained for analysis. These included upper respiratory symptoms (blocked or runny nose, sore throat, sneezing), chest infections (coughing, sputum, chest congestion, wheezing, fever) and gastrointestinal infections (nausea, vomiting, diarrhoea, abdominal pain). Each event was broadly categorised as either respiratory or gastrointestinal symptoms. The number of days of symptoms of each illness event was recorded. Rolling one, three and seven day averages for total training volume, the volume of high-intensity training and the volume of strength/power/sprint training were calculated. Training impulse [16] (TRIMP = training duration (min) x intensity (HR zone 1-5), Training Monotony (mean TRIMP / SD TRIMP) and Training Stress (TRIMP x training monotony) scores [17] were also calculated. In addition, the number of competitions, number of international flights and number of days at altitude (≥1,500 metres above sea level (masl)) during the previous one, three, and seven days were calculated.

Statistical analysis

To explore which factors were associated with onset of illness, multilevel modelling was employed using MLwiN software (version 2.32; University of Bristol). Multilevel logistic regression equations were constructed to predict illness incidence, which was treated as a binary (0=did not become ill, 1=did become ill) outcome variable. Firstly, we explored whether illness events occurred more frequently for males compared with females (0=males, 1=female), for athletes of different performance levels (0=IL, 1=WL), during different times of year (spring (March-May), summer (June-August), autumn (September-November) and winter (December-February)) and during different training phases (transition phase, general preparation phase, specific preparation phase, competition phase, regeneration phase) by including these as categorical independent variables in separate multilevel models. Training variables, air travel, altitude exposure and competition were entered into separate models as independent variables to determine unadjusted odds ratios. In order to disaggregate within-person and between-person associations, each participant's aggregate for each variable was centred on the grand mean and entered into the level 2 equation to determine whether an individual with higher average values for that independent variable had a higher incidence of illness, compared to an individual with lower average values (between-person relationships). Each variable was also centred on each participant's unique mean and entered into the level 1 equation to determine whether fluctuations around an individual's average were associated with changes in illness incidence (within-person relationships). Odds ratios for training variables represent the increase in risk of an illness event occurring as a result of a 1 h/week increase in that training variable, or a 10% increase in Training Monotony, Training Stress and TRIMP. Based on the unadjusted models described above, adjusted logistic multilevel models were constructed with all significant independent variables from the unadjusted models included. Multilevel regression equations were also constructed to determine whether sex, performance level, type of illness, season, training phase or training load during illness were significantly associated with duration of symptoms. Significance was accepted at the $P<0.05$ level.

RESULTS

Data for 7,016 person-weeks were analysed. These included 464 events of illness, 110,959 h of training, 3,812 competitions, 1,769 international flights and 4,879 days at altitude >1,500 masl. Of all the training recorded, 91% was endurance training and 9% was strength/power/sprint training (Table 2). Of endurance training, 90% was at low intensity (I-zone 1 and 2), and 10% was at high intensity (I-zone 3-5).

Illness incidence

In total, athletes reported 464 illness events, equivalent to median (range): 3.4 (0.6-6.8) events and 19 (6-43) days of illness per athlete per year. Of these, 410 events were RTI, equivalent to 3.0 events per athlete per year, and 54 events were GII, equivalent to 0.4 events per athlete per year The average duration of symptoms was 5 ± 4 days, with this being significantly longer for RTI compared to GII (5 ± 4 vs. 3 ± 2 days, b=-1.294, P<0.001).

Risk factors for illness

Unadjusted and adjusted odds ratios for illness for all the candidate risk factors are presented in Tables 3 and 4. Analysing respiratory symptoms separately from gastrointestinal symptoms did not affect which variables were associated with illness.

Sex and performance level

Sex was not a significant risk factor for either illness incidence or symptom duration. However, performance level was significantly associated with the duration of symptoms, with this being lower for WL athletes (b=-0.019, P=0.034). Consequently, WL athletes reported a lower total number of days of illness per year compared with IL athletes (median (range): 14 (6-29) days/year vs. 22 (8-43) days/year), despite no significant between-group differences in training load, number of flights, competitions or days spent at altitude.

Table 2: Training variables and illness events by sex, performance level, training phase and season during 7,016 person-weeks for 37 elite cross-country skiers.

FACTOR	ENDURANCE					Str/Pw	Sprint	Daily training volume (h:min)	Daily TRIMP	Illness events (% of weeks)	RTI events (% of weeks)	GII events (% of weeks)	Weeks (% of factor)
	I-zone 1	I-zone 2	I-zone 3	I-zone 4	I-zone 5								
TOTAL	79%	3%	4%	3%	2%	8%	2%	02:20 ± 01:19	192 ± 114	6.6	5.8	0.8	7016 (100%)
SEX													
Male	78%	4%	4%	3%	2%	7%	1%	02:11 ± 01:20	181 ± 116	7.4	6.6	0.8	3402 (48%)
Female	79%	3%	3%	3%	2%	8%	2%	02:28 ± 01:18	203 ± 111	5.9	5.2	0.7	3614 (52%)
PERF. LEVEL													
IL	78%	4%	4%	3%	2%	7%	2%	02:14 ± 01:20	187 ± 115	7.4	6.7	0.7	3298 (47%)
WL	80%	3%	3%	3%	2%	7%	2%	02:24 ± 01:19	197 ± 112	5.9	5.1	0.8	3718 (53%)
PHASE													
Transition	76%	5%	4%	2%	1%	11%	1%	02:15 ± 01:16	183 ± 108	7.3	6.5	0.8	629 (9%)
General prep.	78%	4%	4%	3%	1%	8%	2%	02:42 ± 01:24	221 ± 116	5.3	4.9	0.4	3150 (45%)
Specific prep.	81%	2%	3%	3%	3%	7%	1%	02:16 ± 01:08	186 ± 96	6.7	5.6	1.1	1252 (18%)
Competition	81%	2%	3%	4%	4%	5%	1%	01:53 ± 01:03	162 ± 108	8.6	7.5	1.1	1673 (24%)
Regeneration	76%	5%	3%	4%	3%	9%	0%	01:10 ± 01:07	102 ± 116	7.7	6.7	1.0	312 (4%)
SEASON													
Spring	77%	4%	4%	3%	3%	8%	1%	01:50 ± 01:14	155 ± 118	8.0	7.3	0.6	1404 (20%)
Summer	79%	4%	4%	2%	1%	8%	2%	02:44 ± 01:26	222 ± 117	4.1	3.8	0.4	1887 (27%)
Autumn	79%	3%	4%	3%	1%	8%	2%	02:34 ± 01:18	210 ± 109	6.5	5.6	0.9	1901 (27%)
Winter	81%	2%	3%	3%	4%	6%	2%	01:06 ± 01:07	171 ± 99	8.3	7.1	1.2	1824 (26%)

For endurance training in each of the five intensity zones, strength/power (Str/Pw) and sprint training values are percentages of total training volume. Daily training volume and daily Training Impulse (TRIMP) are presented as mean ± SD.
IL: International level athletes; WL: World-leading athletes (minimum one individual senior Olympic/World Championship medal)

Table 3: Unadjusted odds ratios for illness for each predictor variable

Predictor variable	Estimated odds ratio (95% CI)	
	Within subject	Between subject
Sex (M=0)		0.78 (0.60-1.02)
Performance level (IL=0)		0.83 (0.63-1.10)
Summer	1.00	
Autumn	**1.63 (1.23-2.16)***	
Winter	**2.09 (1.59-2.73)***	
Spring	**2.00 (1.50-2.65)***	
General Preparation Phase	1.00	
Specific Preparation Phase	1.28 (0.99-1.65)	
Competition Phase	**1.68 (1.35-2.09)***	
Regeneration Phase	**1.56 (1.02-2.37)#**	
Transition Phase	**1.40 (1.01-1.92)#**	
International air travel	**4.53 (3.49-5.88)***	1.23 (0.19-7.91)
Altitude exposure	**1.05 (1.01-1.10)#**	0.81 (0.52-1.27)
Competition	**2.74 (2.18-3.45)***	0.53 (0.19-1.45)
Total training volume	0.98 (0.97-1.00)	**0.91 (0.85-0.98)#**
High-intensity endurance exercise	**1.16 (1.03-1.31)#**	0.57 (0.30-1.09)
Strength/Power/Sprint exercise	**0.83 (0.75-0.91)***	0.70 (0.48-1.02)
Training monotony	1.01 (0.99-1.02)	**0.86 (0.79-0.93)***
Training impulse	1.00 (0.98-1.01)	1.06 (1.00-1.12)
Training stress	1.00 (1.00-1.00)	**0.97 (0.96-0.99)#**

Data for 7016 person-weeks from 37 elite cross-country skiers.

* P<0.001; # P<0.05

Table 4: Adjusted odds ratios for illness for predictor variables retained in the final multilevel model

Predictor variable	Estimated odds ratio (95% CI)	
	Within subject	Between subject
FIXED EFFECTS		
Intercept	-5.116*	
PREDICTOR VARIABLES		
Summer	1.00	
Autumn	**1.65 (1.20-2.25)***	
Winter	**1.91 (1.11-3.27)***	
Spring	**2.09 (1.09-3.99)***	
General Preparation Phase	1.00	
Specific Preparation Phase	0.70 (0.46-1.04)	
Competition Phase	0.78 (0.46-1.34)	
Regeneration Phase	0.97 (0.46-2.04)	
Transition Phase	0.88 (0.44-1.75)	
International air travel	**4.94 (3.74-6.53)***	2.65 (0.16-44.7)
Altitude exposure	1.05 (1.00-1.10)	0.76 (0.38-1.53)
Competition	**2.93 (2.24-3.83)***	0.55 (0.16-1.92)
Total training volume	1.01 (0.98-1.04)	1.06 (0.90-1.15)
High-intensity endurance exercise	1.08 (0.95-1.24)	0.80 (0.37-1.76)
Strength/Power/Sprint exercise	0.93 (0.83-1.05)	0.82 (0.51-1.33)
Training monotony	1.01 (1.00-1.01)	**0.87 (0.73-1.00)#**
RANDOM EFFECTS		
Intercept	0.066	
R^2	0.347	

Data for 7016 person-weeks from 37 elite cross-country skiers.

* *P*<0.001; # *P*<0.05

Time of year

Athletes experienced significantly more illness events during autumn, winter and spring compared with summer, with the highest probability of illness during the winter months (odds ratio (95% CI): 2.09 (1.59-2.73), $P<0.001$ vs. summer). However, when adjusted for other independent variables, the highest risk of illness was in the spring (odds ratio (95% CI): 2.09 (1.09-3.99), $P<0.001$ vs. summer). Regarding training phase, the highest probability of illness was during the Competition Phase which was from January to March (odds ratio (95% CI): 1.68 (1.35-2.09), $P<0.001$ vs. General Preparation Phase), but training phase was no longer a significant risk factor when accounting for other variables. Season was also significantly associated with symptom duration, with illnesses contracted during autumn ($b=0.024$, $P<0.01$), winter ($b=0.043$, $P<0.001$) and spring ($b=0.037$, $P<0.001$) typically persisting for longer than those reported during the summer.

Competition, air travel and altitude exposure

International air travel was associated with unadjusted odds ratios of 4.53 (3.49-5.88) of becoming ill within the next day, 2.73 (2.25-3.31) of becoming ill within the next three days and 1.78 (1.52-2.06) of becoming ill within the next seven days (all $P<0.001$). When accounting for other independent variables, air travel was associated with adjusted odds ratios of 4.94 (3.74-6.53), 2.66 (2.17-3.26) and 1.59 (1.36-1.85) of becoming ill within one, three and seven days, respectively (all $P<0.001$). Indeed, 35% of all recorded illness events were associated with an international flight during the preceding 72 h. Of the 1769 flights recorded, 53% were outbound and 47% were homebound, while 95% were continental and 5% intercontinental. Homebound flights were more likely to be associated with a subsequent illness event compared with outbound flights (14% vs. 5%) and intercontinental flights were more likely to be associated with a subsequent illness event compared with continental flights

(17% vs. 9%).Taking part in a competition was associated with unadjusted odds ratios of 2.74 (2.18-3.45) of becoming ill within the next day, 1.75 (1.57-1.95) of becoming ill within the next three days and 1.45 (1.35-1.55) of becoming ill within the next seven days (all P<0.001). When accounting for other independent variables, competition was associated with adjusted odds ratios of 2.93 (2.24-3.83), 1.78 (1.56-2.03) and 1.51 (1.38-1.66) of becoming ill within one, three and seven days, respectively (all P<0.001).

Exposure to altitude of ≥1,500 masl was associated with an unadjusted odds ratio of 1.05 (1.01-1.10) (P<0.05) of becoming ill within the next seven days, but was no longer significantly associated with illness when accounting for other independent variables.

Training

The only training variable that was a significant risk factor illness in both unadjusted and adjusted models was Training Monotony. A 10% increase in between-person Training Monotony was associated with an unadjusted odds ratio (95% CI) of 0.86 (0.79-0.93) (P<0.001), and remained significant when accounting for other variables (odds ratio (95% CI): 0.87 (0.73-0.99), P<0.05). In unadjusted models, within-person increases in the volume of strength/power/sprint exercise was negatively associated with illness incidence (odds ratio (95% CI): 0.83 (0.75-0.91) while within-person high-intensity endurance exercise was positively associated with illness incidence (odds ratio (95% CI): 1.16 (1.03-1.31). However, both became non-significant when accounting for other independent variables. Between-person total training volume and Training Stress were both negatively associated with illness incidence in unadjusted models (odds ratio (95% CI): 0.91 (0.85-0.98) and 0.97 (0.96-0.99), respectively) but became non-significant when adjusted for other independent variables. TRIMP was not a significant risk factor for subsequent illness, nor was TRIMP during illness significantly associated with symptom duration.

The final adjusted multilevel model included the following variables, which were found to be significant predictors in the unadjusted models: season, training phase, competition, aircraft travel, altitude exposure, total training volume, volume of high-intensity training, volume of strength/power/sprint training and training monotony.

DISCUSSION

Frequency and timing of illness in elite athletes

Our data indicate that elite winter endurance athletes experience three to four episodes of respiratory and/or gastrointestinal illness per year, with symptoms typically lasting five days. Few other studies have examined illness rates in athletes for periods of more than a few weeks or months. However, Hellard et al. [10] reported a similar frequency of infectious illness for elite swimmers who experienced, on average, four episodes of respiratory, gastrointestinal and/or urogenital infection per person-year. Hence, it appears that elite endurance athletes experience broadly similar illness rates, regardless of whether their competition season falls during the winter or summer months. However, there appears to be high inter-individual variability in illness susceptibility, even within a homogenous group of elite athletes. For the 37 athletes included in the current study, average individual illness rates ranged from 1-7 events per year, despite only minor differences in training load, travel and competition schedule or training environment.

Cross-country skiers report the highest frequency of illness during the winter months, similar to elite swimmers [10] and mirroring seasonal patterns for respiratory illness in the general population [18]. However, when adjusting for other variables such as the number of competitions, spring was associated with the highest risk of illness. However, since these athletes typically train and compete on snow until mid-April, the months categorised as “spring” bear much resemblance to winter. Furthermore, it is during these months that vitamin D levels would be expected to be at their lowest, with recent research indicating that vitamin D deficiency is a predictor of infection in endurance athletes [19]. Since training phase was not a significant risk factor when adjusted for season, and since patterns of illness appear to be similar for summer and winter sport athletes, time of year appears to influence illness risk to a greater degree than which training phase the athlete is in.

Training- and competition-related risk factors

The single biggest risk factor for illness was international air travel, making the athlete approximately five times more likely to experience illness the subsequent day. This is in agreement with previous studies in non-athletes which have reported that ~20% of individuals experience symptoms of respiratory illness within one week of commercial aircraft travel [20] and that cabin staff are more predisposed to respiratory infections than the general population [21]. Air travel is associated with a number of stressors which may increase illness risk. These include: time-zone changes, sleep disruption, increased pathogen exposure due to crowded conditions in airports and on aircraft, mild hypoxia and drying of oral and nasal mucosa, as well as stressful events such as delays and lost luggage. Hence, although often unavoidable, athletes are advised to minimise air travel as much as possible, particularly immediately prior to important competitions and major championships. When competing in central Europe, driving between competition venues may be a preferable alternative to flying, provided the distance is feasible. Where this is not possible, flying out as early as possible prior to a major competition will reduce the likelihood of the athlete experiencing illness during the event itself, although this of course does not ameliorate the risk of illness disrupting the training/tapering process. The finding that homebound flights were associated with greater risk of subsequent illness compared with outbound flights is in contrast with previous findings (REF). However, the majority of homebound flights for these athletes were following a competition weekend, while the outbound flights were usually undertaken in the morning in a more rested state. Often the athletes would fly home in the evening on the same day as the final competition. It is well documented that acute bouts of strenuous and prolonged physical activity results in a number of immune disturbances which persist for a number of hours. Traveling home when already in a somewhat immunocompromised state may

In contrast to the findings of Foster [17] neither TRIMP nor Training Stress were associated with increased illness incidence at the between- or within-person level, when accounting for other risk factors. Although within-person changes in Training Monotony were not significantly associated with illness, those athletes with higher average Training Monotony were somewhat less susceptible to illness than athletes with lower Training Monotony. This finding suggests that a microcycle that avoids large fluctuations in total daily training load may be preferable to one that alternates between very hard and very easy days, at least in terms of reducing illness risk. This is an interesting finding and contrasts with current recommendations that athletes should add variety to limit training monotony [22]. However, typical practice in cross-country skiing does traditionally incorporate “hard” and “easy” training days, so these findings may be indicative that it is more extreme fluctuations above this norm which increase illness risk. Rather than measuring only daily variation in TRIMP, a calculation that also accounts for differences in activity type (e.g. skiing vs. running vs. cycling) would give a more accurate indication of the true training monotony.

None of the other measured training variables were significantly associated with illness incidence when accounting for other independent variables. This is in contrast to Hellard et al. [10] who found that increases in high-load and resistance training augmented the risk of respiratory illness. In the current study, high-intensity endurance exercise was significantly associated with illness only in the unadjusted models. This can likely be explained by the fact that high-intensity endurance exercise was a sum of all recorded time spent in Intensity Zones

3-5, including both interval training and competition. However, since competitions are associated with additional physiological and psychological stress above that typically encountered even during the most intense training sessions, competition was also treated as a separate binary variable (did the athlete compete? Yes/No). Since only competition remained significant in the adjusted model, it appears that some other factor than merely time spent at high-intensity contributes to the increase in illness susceptibility associated with competing. Whether this is related to greater psychological stress, greater physiological stress, environmental factors such as crowd exposure, or a combination of these, is not clear. Whatever the underlying mechanisms, the finding that taking part in competitions increases the risk of illness is in agreement with previous studies [8, 23], although Hellard et al. [10] found that the risk of upper respiratory tract and pulmonary infections in swimmers was higher in the periods of intensive training than in both competition and post-competition periods. Unlike swimmers, however, cross-country skiers perform their most intensive training during the summer and primarily compete during the winter months [6] which may account for this discrepancy.

It is well known that ascent to high altitude alters both physiological and metabolic function, and can influence immune function [12]. However, it is not clear whether the moderate altitudes to which elite endurance athletes are typically exposed results in clinical changes in immunity and illness susceptibility. Tiollier et al. [24] found a cumulative negative effect of physical exercise and hypoxia on salivary secretory immunoglobulin-A (S-IgA) levels in elite cross-country skiers during 18-days of live high, train low altitude training. Since reduced S-IgA levels have been consistently linked to increased risk of upper-respiratory symptoms [25, 26] it is likely that such a reduction would make athletes more susceptible to illness. However, the current results suggest that altitude exposure does not significantly increase the risk of an athlete becoming ill when other factors, such as air travel to and from the altitude camp, are accounted for.

Performance level and sex

In the current study, the athletes of the highest performance level experienced a lower total number of annual illness days compared to athletes of a lower performance level. Although it is not possible to determine cause and effect, this is in accordance with the findings of Hellard et al. [10] that swimmers of a higher performance level had a lower risk of upper-respiratory tract infections, suggesting that a robust immune system capable of withstanding and recovering quickly from illness, even during periods of high physiological, psychological and environmental stress, may be a predictor of success in an otherwise homogenous group of elite athletes.

Although, in the general population, men appear to be somewhat more susceptible to viral and bacterial infections than women [27] recent studies of athletes suggest a higher incidence of respiratory illnesses amongst females compared to males [28-31]. However, in the current study, sex was not significantly associated with either illness incidence or symptom duration.

Limitations

The current dataset includes a large amount of data for some of the world's best winter endurance athletes. However, a clear limitation is that both training and illness data was self-reported. Although elite cross-country skiers have previously been found to self-report their training accurately [32], only 79% of 159 respiratory illnesses reported by athletes during the Sochi Olympic Games were due to infection [31]. Since not all symptoms in the current study were verified by a physician, it is likely that some of the illness events included in analyses were due to non-infectious causes. It is also possible that elite athletes are more/less apt to self-report illness than the general population. However, since the current analyses are based only on comparisons within and between individuals from the same athlete group, a reporting bias is unlikely to be of major concern.

CONCLUSION

World-class cross-country skiers experience 3-4 illness events per year, with symptoms typically lasting 5 days. The highest illness rates for these athletes occur during the winter months. However, world-leading athletes experience fewer illness days per year compared to athletes of a lower performance level. Air travel and taking part in competitions both significantly increase the risk of illness. Since both are inherent components of international-level sport, future research exploring effective strategies to minimise illness risk associated with competition and air travel is warranted. In terms of reducing illness susceptibility, a microcycle that avoids large fluctuations in total daily training load may be preferable.

What are the new findings?

- Elite winter endurance athletes typically experience 3-4 illness events per year, with the highest illness rates occurring during winter months. This is similar to annual patterns of illness reported for summer sport athletes.
- Air travel and competition markedly increase the risk of illness.
- Large day-to-day fluctuations in training load appear to make an athlete more susceptible to illness.
- World/Olympic medal-winning athletes report fewer annual days of illness than less successful athletes.

How might it impact on clinical practice in the near future?

- Athletes, coaches and support staff should be aware of the times when athletes are particularly prone to illness (winter months and periods of competition and travel). Implementing effective hygiene procedures, promoting adequate recovery and optimising the nutritional status of athletes should be a particular priority at these times.
- Athletes should avoid unnecessary air travel and excessive competition in the lead up to important events.
- Athletes are advised to avoid extreme day-to-day fluctuations in training load.

FOOTNOTES

Contributors: ISS was involved in the study's design, data collection, analysis and interpretation, drafted and revised the manuscript, and approved the final version. IMT was involved in the data analysis and interpretation, critically revised the manuscript and approved the final version. ET developed the idea, critically revised the manuscript and approved the final version. RB was involved in the study's design, critically revised the manuscript and approved the final version., MG was involved in the study's design, interpretation, critically revised the manuscript and approved the final version.

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