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Original article

Training load characteristics and injury and illness risk identification in elite youth ski racing: A prospective study

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Abstract

Purpose: The study aimed to investigate the role of training load characteristics and injury and illness risk in youth ski racing.
Methods: The training load characteristics as well as traumatic injuries, overuse injuries, and illnesses of 91 elite youth ski racers (age = 12.1 ± 1.3 years, mean ± SD) were prospectively recorded over a period of 1 season by using a sport-specific online database. Multiple linear regression analyses were performed to monitor the influence of training load on injuries and illnesses. Differences in mean training load characteristics between preseason, in-season, and post-season were calculated using multivariate analyses of variance.
Results: Differences were discovered in the number of weekly training sessions ($p = 0.005$) between pre-season (4.97 ± 1.57) and post-season (3.24 ± 0.71), in the mean training volume ($p = 0.022$) between in-season (865.8 ± 197.8 min) and post-season (497.0 ± 225.5 min) and in the mean weekly training intensity (Index) ($p = 0.012$) between in-season (11.7 ± 1.8) and post-season (8.9 ± 1.7). A total of 185 medical problems were reported (41 traumatic injuries, 12 overuse injuries, and 132 illnesses). The weekly training volume and training intensity was not a significant risk factor for injuries ($p > 0.05$). Training intensity was found to be a significant risk factor for illnesses in the same week ($\beta = 0.348$; $p = 0.044$; $R^2 = 0.121$) and training volume represents a risk factor for illnesses in the following week ($\beta = 0.397$; $p = 0.027$; $R^2 = 0.157$).
Conclusion: A higher training intensity and volume were associated with increased illnesses, but not with a higher risk of injury. Monitoring training and ensuring appropriate progression of training load between weeks may decrease incidents of illness in-season.

Keywords: Health problems; Injury and illness prevention; Training load; Youth ski racing

1. Introduction

Alpine ski racing has become a popular sport among children in Austria, and a strong focus has therefore been placed on youth developmental programs, including injury prevention. A large number of specialized ski boarding schools for talented young athletes provide a fundamental basis for a future professional career.[1] Although regular sports activities at a young age have health benefits, there is a growing risk of suffering an injury that may counteract these beneficial effects.[2] Existing research indicates that athletes are more likely to sustain injuries due to inappropriate training loads during growth.[3] Alpine skiing is a late specialization sport, and the peak performance in alpine ski racing is mostly achieved between the ages of 26 and 28 years.[4]

However, specialization at an early age combined with an athlete's long competitive life needs to be considered when implementing strategies to develop talents. Huxley et al.[5] showed that there is a relationship between high volumes of training in 13- to 14-year-old cricket bowlers and early retirement due to injuries. Previous research in adolescent and adult sports activities such as soccer, basketball, and Australian football has proven the correlation between a higher number of injuries and spikes in training loads or chronically high workloads and intensities.[6−8] However, these data refer to older athletes, and research on youth athletes are missing.

General recommendations exist for coaches working with youth athletes. These include avoiding specialization in only

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1 sport at an early age and restricting the organized training to less than 8 months per year and to fewer hours a week than a child's age.[9,10] However, sport-specific recommendations are missing for alpine ski racing, even though this is a sport with a generally high risk of injury.[11]

A further challenge in youth sport specializations is the dual management of the training programs and academic commitments.[12] Physiologic and psychological overload combined with inappropriate regeneration may have a negative effect on the immune system. Previous research in adults has suggested that higher volumes of exercises are associated with an increased infection rate.[13] However, it can be assumed that young athletes may adapt differently to comparable training volumes and intensities than older and more experienced athletes, but there is a paucity of research on youth athletes that examines the relationship between training characteristics and illness. Consequently, the purpose of the present study was to prospectively examine training load as it relates to the occurrence, severity, and burden of injuries and illnesses in youth alpine ski racers.

2. Methods

2.1. Study design

All procedures were approved by the Institutional Review Board of the Department of Sport Science at the University of Innsbruck and by the Board for Ethical Questions at the University of Innsbruck. A 1-season prospective study design was used to record traumatic injuries, overuse injuries, illnesses, and training characteristics in a cohort of elite youth alpine ski racers. Analyzed data from the season were evaluated from the beginning of the school in September, 2017 to the end of the training in May, 2018. Data from each week of the study period were analyzed, except for 1-week vacations in December, February, and April. A total of 32 training weeks (holiday weeks were not considered) were analyzed, which were divided into the following training phases: pre-season (6 weeks), in-season (20 weeks), and post-season (6 weeks). The pre-season training phase was defined as the period between the start of the school until the first skiing competition. Likewise, the post-season was defined as the end of the regular skiing competition season until the end of May. The weeks in between were defined as the in-season period and included all competitions. To record training characteristics, a sport-specific, Internet-based database was developed (innjury.net). All data were systematically checked with the coaches and physiotherapists either by e-mail or by telephone. When uncertain or missing information was identified, direct verification with either the coaches, parents, a medical attendant, or a physiotherapist was done. In cases where all relevant information could not be collected, the data were excluded from the data analysis. The general methodology has been reported elsewhere.[14]

2.2. Participants

All athletes were recruited from a skiing boarding school in Austria. To attend this school, the pupils had to pass an entrance examination that included both skiing-specific and general physical performance tests, as well as successfully complete exercises related to alpine skiing. Following these tests, a maximum of 22 of the best-performing pupils each year were eligible to attend the school. Participants, parents, and coaches were given a clear explanation of the study design, including the risks and benefits. All parents of the pupils ($n = 92$) who were eligible for the study agreed to the study and provided their written consent. Throughout the 1-season period, 1 athlete (male) left the school; therefore, a total of 91 elite youth ski racers (52 males, 39 females) between the ages of 10 and 14 years who were free of acute injury at the beginning of the study were enrolled. The anthropometric characteristics for male and female athletes are presented in Table 1.

2.3. Data collection

2.3.1. Injury registration

As previously reported,[14] all injuries and illnesses were included in the data analyses as soon as they resulted in a restriction to full participation in training for at least 1 day. Each athlete's health problems were recorded by that athlete's particular coach on a daily basis. A medical report was included in the database where provided. Following the approach of Brooks and Fuller,[15] a traumatic injury was defined as an injury with a sudden onset. Overuse injuries were defined as any physical complaint without a single identifiable event being responsible. The severity of injuries and illnesses was calculated based on the number of absence days, classified by Clarsen et al.[16] as minimal (1−3 days), mild (4−7 days), moderate (8−28 days), and severe (>28 days). Injury incidence was calculated as the number of injuries per 1000 h of exposure. In addition, as suggested by Bahr et al.,[17] injury burden combines the rate and the measure of loss and was therefore calculated as the number of injury days lost per 1000 h of training.

2.3.2. Training characteristics and competitions

Using the training database, the coaches immediately recorded external measures after each training session (Table 2). These sessions were divided into skiing-specific and athletic-specific (off-snow) training. The intensity of each training session was constantly recorded to provide a rating of perceived exertion. The coaches rated each session as a daily group average using the following scale: 1 = *easy*, 2 = *moderate*, 3 = *intense*, and 4 = *very intense*.[5] The number of sessions in each intensity category was multiplied by the assigned coefficient for each category. The overall weekly intensity was then calculated as the sum of the calculated intensity sessions, for example, $(2 \times 1) + (1 \times 2) + (2 \times 3) + (1 \times 4) = 14$. In addition, a weekly and monthly average of training load (in minutes) was calculated

Table 1
Anthropometric characteristics of male and female athletes (mean ± SD).

	Male ($n = 52$)	Female ($n = 39$)
Age (year)	12.1 ± 1.3	12.0 ± 1.3
Height (cm)	152.6 ± 9.8	152.4 ± 10.0
Weight (kg)	42.7 ± 8.8	43.5 ± 9.7
BMI (kg/m^2)	17.9 ± 2.0	18.5 ± 2.3

Abbreviation: BMI = body mass index.

to provide an acute:chronic workload ratio. To calculate this ratio, the training data were grouped into weekly blocks (Monday to Sunday). The calculated average 1-week training load (i.e., 480 min) represented the acute workload. The chronic workload was calculated as the 4-week rolling average acute workload (i.e., 420 min). The ratio was then calculated by dividing the acute workload by the chronic workload (e.g., 480 min divided by 420 min results in a ratio of 1.14). Therefore, a value above 1 represents a higher acute workload than chronic workload, and a value below 1 represents a higher chronic workload than acute workload.

2.4. Statistical analyses

Descriptive statistics are presented as a mean ± SD for continuous variables and as frequency counts and percentages for categorical variables. The rate of injuries and illnesses per athlete was calculated as the number of injured and ill ski racers divided by the total number. The incidence per 1000 h of training was assessed by the number of injuries and illnesses divided by the total number of hours of exposure of all athletes multiplied by 1000. Multiple linear regression analyses with stepwise backward elimination were performed to identify the influence of training load characteristics on injuries and illnesses. The regression analyses were calculated twice, with injuries and illnesses in the same week as well as injuries and illnesses in the following week. Differences in mean training load characteristics between pre-season, in-season, and post-season were calculated using multivariate analyses of variance. The level of significance was set at $p < 0.05$. All calculations were performed using SPSS Version 25.0 (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Training load characteristics

A total of 666 training sessions were analyzed (311 athletic specific and 355 skiing specific; Table 2). The mean weekly training volume of skiing-specific training sessions with free-skiing exercises was 344.8 ± 196.6 min, and the mean weekly training volume of skiing-specific training sessions with gates was 382.8 ± 166.3 min. The total mean number of competitions during the season was 16.4 ± 8.8 for males and 16.8 ± 9.6 for female ski racers. With respect to the rating of perceived exertion, most athletic training sessions were intense (46.6%), followed by moderate (39.9%), highly intense (10.4%), and easy (3.1%). Most skiing-specific training sessions were defined as intense (69.3%) or highly intense (16.1%), and 14.6% were rated as moderate. The analyses of variance showed significant differences in the number of weekly training sessions ($F = 6.54$, $p = 0.05$), weekly mean training volume (in minutes) ($F = 4.43$, $p = 0.021$) and weekly mean training intensity (index) ($F = 5.19$, $p = 0.012$) between pre-season, in-season, and post-season. *Post-hoc* tests revealed differences in weekly training sessions ($p = 0.005$) between pre-season (4.97 ± 1.57) and post-season (3.24 ± 0.71) and in the mean training volume ($p = 0.022$) between in-season (865.8 ± 197.8 min) and post-season (497.0 ± 225.5 min), as well as in the mean weekly training intensity ($p = 0.012$) between in-season (11.7 ± 1.8) and post-season (8.9 ± 1.7).

Table 2
Training characteristics of skiing- and athletic-specific training sessions (mean ± SD).

	Total	Skiing	Athletic
Total exposure time per season (h)	425.3	318.1	107.2
Mean training volume per week (min)	790.0 ± 296.8	734.0 ± 232.7	201.1 ± 122.0
Mean number of training sessions per week (*n*)	5.1 ± 1.0	2.9 ± 0.8	1.8 ± 1.0
Mean training intensity per week	11.0 ± 2.1	7.7 ± 3.5	4.8 ± 3.2

The total mean weekly training volume is presented in Fig. 1. A low training volume was applied during the first 3 training weeks, followed by high-volume training at the end of the preparation phase. Within the first 7 weeks of the in-season weeks (Weeks 7−13), there was a high fluctuation in training volume, followed by a relatively constant volume until the end of in-season weeks (Weeks 14−26). In the post-season period, the training volume was lowest (Weeks 27−32). The total weekly training intensity is presented in Fig. 2. The analysis of the training intensity resulted in a pattern similar to that of the volume. There was a low intensity of training at the beginning, followed by a high intensity at the end of the preparation phase and at the beginning of the competition season, and a relatively constant intensity during the competition season. The linear regression analyses showed that the weekly number of training sessions, weekly training volume, and training intensity did not represent a significant risk factor for traumatic and overuse injuries ($p > 0.05$). However, training intensity was found to be a significant risk factor for illnesses in the same week ($\beta = 0.348$; $p = 0.044$, $R^2 = 0.121$), and training volume represents a risk factor for illnesses in the following week ($\beta = 0.397$; $p = 0.027$, $R^2 = 0.157$).

3.2. Traumatic injuries, overuse injuries, and illnesses

A total of 185 medical problems were reported, with an injury incidence rate for all injuries of 1.4 injuries per 1000 h of training.

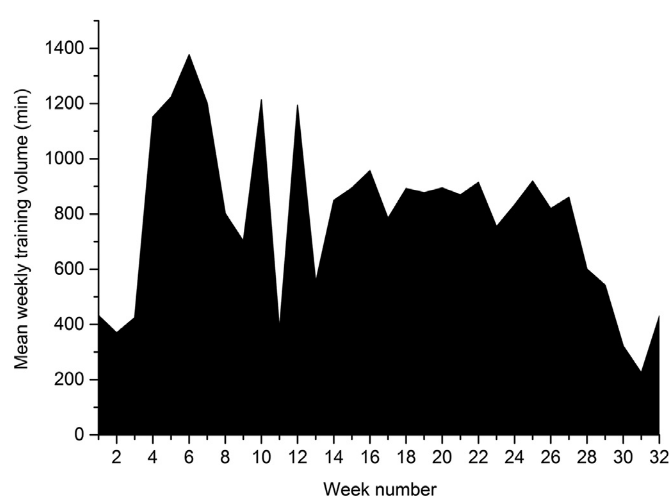

Fig. 1. Mean weekly training volume in a 32-week season for youth ski racers.

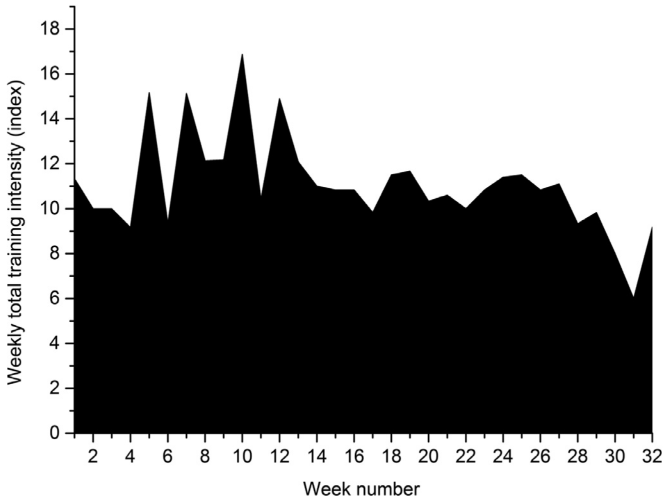

Fig. 2. Mean weekly training intensity in a 32-week season for youth ski racers.

3.2.1. Traumatic injuries

Of these injuries, 41 traumatic injuries (0.45 injuries/athlete) were recorded, representing an incidence of 1.1 per 1000 h of training. The 41 traumatic injuries were reported by 31 athletes (10 females and 21 males). Most of these traumatic injuries were categorized as moderate (36.6%) or mild (31.7%); only 17.1% were severe and 14.6% were minimal. They occurred either during skiing-specific training (43.9%), during leisure sport activities, or during athletic training sessions (22.0%); 9.7% occurred during competitions. The location and type are shown in Table 3.

3.2.2. Overuse injuries

A total of 12 overuse injuries (0.13 injuries/athlete) were reported, with an incidence of 0.3 injuries per 1000 h of training. The 12 overuse injuries were reported by 8 athletes (3 females and 5 males) and mostly affected the knee (47.8%), followed by the upper lumbar spine (36.4%). Most overuse injuries were mild (41.7%); others were minimal or severe (25.0%) and only 8.3% were moderate. Most of overuse injuries were new (92.7%), 4.9% were recurrent, and 2.4% were unknown. For both traumatic and overuse injuries, the highest burden was found in the post-season (46.9 absence days/1000 h of training), followed by in-season injuries (21.5 absence days/1000 h of training).

Table 3
Traumatic injuries for all ski racers

Traumatic injuries	Total *n* (%)
Injury location	
Knee	16 (39)
Lower leg	7 (18)
Ankle	5 (12)
Spine/back	4 (10)
Upper leg	3 (7)
Hip	2 (5)
Foot	2 (5)
Head	1 (2)
Shoulder	1 (2)
Injury type	
Contusion	14 (34)
Fracture	12 (30)
Sprain	6 (15)
Strain	3 (7)
Rupture of the meniscus	2 (5)
Rupture of the anterior cruciate ligament	2 (5)
Laceration	1 (2)
Concussion	1 (2)
Total injuries	41 (100)

3.2.3. Illnesses

A total of 132 illnesses (1.45 illnesses/athlete) was found, with an incidence of 3.4 illnesses per 1000 h of training. The 132 illnesses were reported by 69 athletes (29 females and 40 males). Most illnesses consisted of gastrointestinal problems (48.5%), followed by respiratory tract infections (40.3%). The illnesses were categorized as either minimal (55.3%), mild (40.9%), or moderate (3.8%). The highest illness burden was found to be in-season (12.4 absence days/1000 h of training), followed by the post-season (11.7 absence days/1000 h of training).

3.2.4. Acute:chronic workload according to injuries and illnesses

A higher acute training load was found during the weeks with the highest rate of illnesses (acute:chronic workload ratio, 1.93) and the week before the highest rate of illnesses (1.41) compared to the weeks with the lowest rate of illnesses, whereas no relation was found for the rate of injuries (overuse and traumatic). The total number of weekly traumatic injuries and the corresponding acute:chronic workload ratio are shown in Fig. 3, with the total number of weekly illnesses and the acute:chronic workload ratio shown in Fig. 4.

4. Discussion

4.1. Training load characteristics in youth alpine ski racers

The present study investigated the relationship between training load characteristics and the occurrence of injuries and illnesses. Weekly training volume and training intensity did not represent a significant risk factor for traumatic and overuse

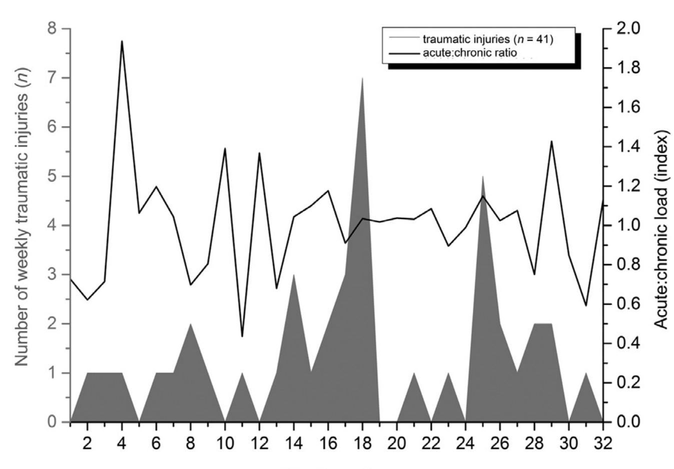

Fig. 3. Number of weekly traumatic injuries (grey) and the corresponding acute: chronic workload ratio (black) during a 32-week season for youth ski racers.

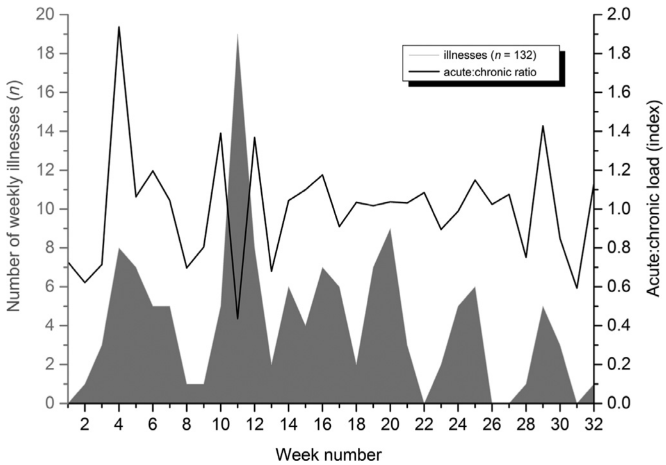

Fig. 4. Number of weekly illnesses (grey) and the corresponding acute: chronic workload ratio (black) during a 32-week season for youth ski racers.

injuries, but training intensity did affect illnesses in the same week and training volume was a risk factor for illnesses in the following week. The mean total training volume was 5.1 training sessions and 790.0 min (13.2 h) per week. The position statement guidelines from the American Medical Society for Sports Medicine recommends that youth athletes should not spend more hours of training per week than their age.[18,19] The average age of the ski racers was 12.1 years; therefore, the training volume of 13.2 h/week was slightly above the American Medical Society for Sports Medicine recommendations. In addition, the training volume for the young alpine ski racers was higher compared to the exposure reported in other youth sports, such as track and field athletics (5.69 ± 2.53 h/week).[20] However, results of the present study include all kinds of training and not only sport-specific training. As expected, the training of the young ski racers was lower compared to the training hours for World Cup elite ski racers.[21] The number of weekly training sessions for Olympic ski racers ranges from 10 to 14 training sessions and a total of 14 to 21 h. The athletic training of the young ski racers includes not only classical strength and coordination training, but also a wide variety of physical activities, including cycling, running, swimming, rollerblading, and team sports (soccer, basketball, and hockey). However, most of the injuries (43.9%) occurred during skiing-specific training. With this in mind, coaches should focus on skiing-specific injury prevention.

4.2. Relationship between training load characteristics and injuries

Previous research on young athletes has shown that the injury incidence ranges from 1 to 12 injuries per 1000 h of training, with most injuries categorized as severe.[22] The incidence of traumatic injuries in the present study was 1.1 per 1000 h of training, a relatively low incidence compared to other studies involving alpine ski racing among adolescents (14−18 years of age) ski racers (males: 1.62 injuries/1000 h of training; females: 1.77 injuries/1000 h of training),[23] but was in line with previous research in youth (10−14 years of age) ski racing (0.86 injuries/1000 h of training).[14] A closer look at the type of injury in the present study reveals a very low incidence of overuse injuries (0.30/1000 h of training), which was also reported previously by Müller et al.[14] (0.28 injuries/1000 h of training). Guidelines in youth sport suggest avoiding peaks in the training load of more than 10%.[20] There were peaks of more than 10% in the present study, especially during the last period of the pre-season, where the highest increase in volume was found to be up to 15%. However, despite this increase, overuse injuries were not reported frequently in the following weeks. There may be 2 reasons for this. First, coaches were advised to focus on general athletic training and to avoid excessive jumps during the pre-season, as these were found to be responsible for a high rate of knee overuse injuries (anterior knee pain) in a cohort of adolescent athletes.[24] Therefore, coaches were advised to administer low-impact training to enable the passive structures to adapt at the beginning of the training. Second, coaches were aware of the implementation of injury prevention based on discussions and lectures prior to the start of the study. In line with other studies in alpine ski racing, the knee was most frequently affected.[23,25] Among elite alpine ski racers, the anterior cruciate ligament is frequently ruptured in the event of an injury (e.g., 13.6% of all diagnoses at the World Cup level[25] and 15% in adolescent alpine ski racers[26]). However, the findings in the present study showed that bone fractures (5 fractures), including physeal fractures, were more common than ruptures of the anterior cruciate ligament (2 ruptures). Bone fractures are common in children, and the characteristics of the growing skeleton make young athletes susceptible to specific fractures that do not occur in adults.[27] Moreover, it can be assumed that the physis is weaker than ligaments, so that fractures are more likely to occur than a rupture of the anterior cruciate ligament.[28]

Not only is the type of the injury of special interest, but so is information about when the highest risk of injury occurs during a full season. Gabbett[29] found that injury rates were highest during the pre-season in semi-professional rugby players. Likewise, Owen et al.[30] found that there seems to be a positive relationship between the training load and probability of sustaining an injury in elite level professional soccer players during the preseason. These findings were not consistent with our results. In our study, both traumatic and overuse injuries were lowest at the beginning of the season, showing that coaches were aware that appropriate training volumes and intensities allow an athlete to adapt physiologically. The incidence of injuries in the present cohort was highest between Weeks 12−19 (in-season), with a clear peak in Week 18 and Weeks 24−30 (post-season). Most injuries occurred during skiing-specific training. Our findings indicate that there is a higher risk of sustaining an injury not only during the competition season, but also at the end of the season. The high incidence of traumatic injuries in Week 18 can only be explained speculatively. All injuries in this week occurred on different days and only during skiing-specific training and not during competitions. This may be due to the fact that bad weather conditions on the slopes were present (i.e., limited visibility, icy slopes). However, we cannot provide detailed information about this possibility.

In addition, when considering the burden of the traumatic injuries, it becomes evident that they cause the greatest problem, especially during the post-season. Knowing that the exposure on snow is less between Weeks 24−30 compared to in-season training, this is an important finding that should be considered for a general training program. When the competition season is over but there is still ongoing training on snow, the weather conditions might not be the best and the risk of sustaining an injury due to external factors such as snow quality and the resulting poor quality of the slopes might be greater.

Another key finding in the present study was that volume and intensity did not represent a risk factor for injuries. Malisoux et al.[31] found that only training intensity, and not training volume, was associated with a higher injury risk in young rugby players. It can be assumed that the skiing-specific training in particular may be insufficiently intense to contribute to a higher risk of injury. It would appear that the greater risk comes from exposure and external factors, such as snow quality. However, it should be mentioned that the coaches rated the intensity. Rating of perceived exertion is very individualized, and the ski racers may have perceived the intensity of the training differently. This may limit the accuracy of the interpretation. Recent research suggests that the acute (weekly) and chronic (monthly) workload should be considered.[32] Hulin et al.[33] showed that an acute:chronic workload ratio of more than 1.5 increased the risk of injury by 2 to 4 times in the following 7 days for elite cricket bowlers. In contrast with Hulin et al.'s findings, the highest workload ratio in our study was 1.9, but an increase in injury rate in the following week was not observed. However, Hulin et al.[33] investigated elite cricket bowlers, a sport in which it can be assumed that spikes in workloads are more intense due to repetitive sprinting, leading to lactic acidosis and cumulative fatigue. In the youth alpine ski racing occurring in our study, spikes in training volume were mainly due to a focus on technique training and free skiing, which have a relatively low intensity and less accumulation of fatigue.

4.3. Relationship between training characteristics and illnesses

Training intensity was found to be a significant risk factor for illnesses in the same week. The highest rate of illness was found within a period of high-volume, high-intensity training that occurred following the preparation phase (Week 11), meaning that immunosuppression seems to occur following an increase in training intensity and volume. These findings were similar to those of Jones et al.,[27] who found a relationship between a high training load, increased fatigue markers, and an increase in illness in athletes participating in different sports. Furthermore, a higher acute training load was found before the weeks with the highest rate of illnesses compared to the weeks with the lowest rate. This finding is similar to that of Brink et al.,[34] who showed that an increase in the acute training workload resulted in a higher rate of illnesses in youth soccer players.

The highest burden was found to be in-season, causing an average absence of training days of 12.4 per 1000 h of training. However, this phase was in November and December, a period in which the infection rate is generally high. Gastrointestinal infections (48.5%) were more prevalent in the present cohort compared to the findings in other studies using youth athletes, in which respiratory tract infections represented the highest rate of infections.[35] The highest peak of illnesses in Week 11 was caused by a very high rate of gastrointestinal infections (84%). This might be explained by the fact that the risk of infection is highest for gastrointestinal infections that are spread from person to person, especially when the cohort of the young ski racers live close together in the boarding school. Knowing this, preventive procedures, such as exclusion from school and other institutional measures that are kept in place until at least 48 h after the athlete is free of symptoms, adequate hand washing, and the use of paper towels, should be discussed with the coaches and supervising tutors in school. The second highest rate of illnesses was found for respiratory tract infections (40.3%). Previous research has shown that the average adult has 2−4 respiratory tract infections each year and young children have twice as many.[36] Peaks in this kind of infection were predominant in the weeks following holidays, including Christmas holidays (Week 16), winter holidays (Week 22), and Easter holidays (Week 28). It can be assumed that the combination of the start of the training and the get-together of all athletes causes a temporary immunosuppression. In order to reduce the number of infections, the focus should be on preventive measures, such as sufficient regeneration and sleep, as well as healthy nutrition, especially following holidays.

5. Conclusion

The results of the present study should lead to a better understanding of how training load characteristics relate to time of season and health problems in young ski racers and thus help coaches to reduce the risk of injuries and illnesses and to provide adequate training with a long-term beneficial effect. The weekly training volume and training intensity did not represent a significant risk factor for traumatic and overuse injuries. However, training intensity was found to be a significant risk factor for illnesses occurring in the same week and training volume represents a risk factor for illnesses in the following week. A higher acute training load was found before and within the weeks with the highest rate of illnesses, while no differences were found for the rate of injuries. Based on season, the burden of all injuries was highest in the post-season, whereas for illnesses the highest burden was found to be in-season. However, these findings should be interpreted only as a tendency since the injury and illness risk identified here may also be related to a number of additional factors that were not measured. Alpine ski racing is a sport with a high risk of injuries. Therefore, external factors, such as snow quality and weather conditions, should also be considered before any determinations and recommendations are made regarding which part of the ski season has the highest injury and illness risk, as well as which part of the season offers the best opportunities to prevent injury and illness. Future research with young cohorts of athletes should also include measures of internal loads, including school workload, quality of sleep, and regeneration, because these loads measure the combination of physiologic stress and psychological demand. Finally, the ability to draw conclusions from the findings in the present study may be limited by the relatively low number of participants and the total injury rate.

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Authors' contributions

CH devised the study, contributed to the data collection, analyses and interpretation, and drafted most of the manuscript; CR supervised the study design, contributed to the data collection and interpretation, and reviewed the manuscript; RO contributed to the interpretation of the data; EM contributed to the data analysis and interpretation; CF participated in the data collection and contributed to the interpretation of the data; LSM devised the study, contributed to the data collection, analyses, and interpretation, and drafted the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

References

1. Raschner C, Müller L, Hildebrandt C. Talent detection and development in alpine ski racing. In: Müller E, editor. *Science and Skiing VI*. Aachen: Meyer & Meyer Sport; 2015.p.65–75.
2. Maffulli N, Longo UG, Gougoulias N, Loppini M, Denaro V. Long-term health outcomes of youth sports injuries. *Br J Sports Med* 2010;**44**:21–5.
3. Soligard T, Schwellnus M, Alonso JM, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med* 2016;**50**:1030–41.
4. Raschner C, Müller L, Patterson C, et al. Current performance testing trends in junior and elite Austrian alpine ski, snowboard and ski cross racers. *Sport Orthop Sport Traumat* 2013;**29**:193–202.
5. Huxley DJ, O'Connor D, Healey PA. An examination of the training profiles and injuries in elite youth track and field athletes. *Eur J Sport Sci* 2014;**14**:185–92.
6. Gabbett TJ, Whyte DG, Hartwig TB, Wescombe H, Naughton GA. The relationship between workloads, physical performance, injury and illness in adolescent male football players. *Sports Med* 2014;**44**:989–1003.
7. Anderson L, Triplett-McBride T, Foster C, Doberstein S, Brice G. Impact of training patterns on incidence of illness and injury during a womańs collegiate basketball season. *J Strength Cond Res* 2003;**17**:734–8.
8. Veugelers KR, Young WB, Fahrner B, Harvey JT. Different methods of training load quantification and their relationship to injury and illness in elite Australian football. *J Sci Med Sport* 2015;**19**:24–8.
9. Bergeron MF, Mountjoy M, Armstrong N, et al. International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med* 2015;**49**:843–51.
10. Post EG, Trigsted SM, Riekena JW, et al. The association of sport specialization and training volume with injury history in youth athletes. *Am J Sports Med* 2017;**45**:1405–12.
11. Spörri J, Kröll J, Gilgien M, Müller E. How to prevent injuries in alpine ski racing: what do we know and where do we go from here? *Sports Med* 2017;**47**:599–614.
12. Kristiansen E. Walking the line: how young athletes balance academic studies and sport in international competition. *Sport Society* 2016;**20**:47–65.
13. Watson A, Brickson S, Brooks A, Dunn W. Subjective well-being and training load predict in-season injury and illness risk in female soccer players. *Br J Sports Med* 2017;**51**:194–9.
14. Müller L, Hildebrandt C, Müller E, Oberhoffer R, Raschner C. Injuries and illnesses in a cohort of elite youth alpine ski racers and the influence of biological maturity status and relative age: a two-season prospective study. *Open Access J Sports Med* 2017;**8**:113–22.
15. Brooks JH, Fuller CW. The influence of methodological issues on the results and conclusions from epidemiological studies of sports injuries: illustrative examples. *Sports Med* 2006;**36**:459–72.
16. Clarsen B, Rønsen O, Myklebust G, Flørenes TW, Bahr R. The Oslo Sports Trauma Research Center questionnaire on health problems: a new approach to prospective monitoring of illness and injury in elite athletes. *Br J Sports Med* 2014;**48**:754–60.
17. Bahr R, Clarsen B, Ekstrand J. Why we should focus on the burden of injuries and illnesses, not just their incidence. *Br J Sports Med* 2018;**52**:1018–21.
18. Eckard TG, Padua DA, Hearn DW, Pexa BS, Frank BS. The relationship between training load and injury in athletes. A systematic review. *Sports Med* 2018;**48**:1929–61.
19. Brenner JS, Council on Sports Medicine and Fitness. Sports specialization and intensive training in young athletes. *Pediatrics* 2016;**138**:e20162148. doi:10.1542/peds.2016-2148.
20. Henriksen K, Stambulova N, Roessler KK. Successful talent development in track and field: considering the role of environment. *Scand J Med Sci Sports* 2010;**20**:122–32.
21. Gilgien M, Reid R, Raschner C, Supej M, Holmberg HC. The training of Olympic alpine ski racers. *Front Physiol* 2018;**9**:1772–8.
22. Jones CM, Griffiths PC, Mellalieu SD. Training load and fatigue marker associations with injury and illness: a systematic review of longitudinal studies. *Sports Med* 2017;**47**:943–75.
23. Westin M, Alricsson M, Werner S. Injury profile of competitive alpine skiers: a five-year cohort study. *Knee Surg Sports Traumatol Arthroscop* 2012;**20**:1175–81.
24. Hildebrandt C, Raschner C. Traumatic and overuse injuries among elite adolescent alpine skiers. *Int Sport Med J* 2013;**14**:245–55.
25. Flørenes TW, Bere T, Nordsletten L, Heir S, Bahr R. Injuries among male and female World Cup alpine skiers. *Br J Sports Med* 2009;**43**:973–8.
26. Raschner C, Platzer HP, Patterson C, Werner I, Huber R, Hildebrandt C. The relationship between ACL injuries and physical fitness in young competitive ski racers: a 10-year longitudinal study. *Br J Sports Med* 2012;**46**:1065–71.
27. Jones MH, Simon JE, Winell J. Pediatric knee fractures. *Curr Opin Pediatr* 2005;**17**:43–7.
28. Klentrou P. Influence of exercise and training on critical stages of bone growth and development. *Pediatr Exerc Sci* 2016;**28**:178–86.
29. Gabbett TJ. Influence of training and match intensity on injuries in rugby league. *J Sports Sci* 2004;**22**:409–17.
30. Owen AL, Forsyth JJ, Wong DP, Dellal A, Connelly SP, Chamari K. Heart rate based training intensity and its impact on injury incidence amongst elite level professional soccer players. *J Strength Cond Res* 2015;**29**:1705–12.
31. Malisoux L, Frisch A, Urhausen A, Seil R, Theisen D. Monitoring of sport participation and injury risk in young athletes. *J Sci Med Sport* 2013;**16**:504–8.
32. Schwellnus M, Soligard T, Alonso JM, et al. How much is too much? (Part 2) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med* 2016;**50**:1043–52.
33. Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med* 2014;**48**:708–12.
34. Brink MS, Visscher C, Arends S, Zwerver J, Post WJ, Lemmink KA. Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *Br J Sports Med* 2010;**44**:809–15.
35. Svendsen IS, Taylor IM, Tønnessen E, Bahr R, Gleeson M. Training-related and competition-related risk factors for respiratory tract and gastrointestinal infections in elite cross-country skiers. *Br J Sports Med* 2016;**50**:809–15.
36. Cotton M, Innes S, Jaspan H, Madide A, Rabie H. Management of upper respiratory tract infections in children. *S Afr Fam Pract (2004)* 2008;**50**:6–12.