

## ORIGINAL ARTICLE

## Effect of trail design and grooming on the incidence of injuries at alpine ski areas

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*Br J Sports Med* 2004;**38**:264–268. doi: 10.1136/bjism.2002.000270**Objectives:** To identify the conditions at certain sites on slopes known as black spots for injury.**Method:** In the Hafjell and Voss alpine ski areas in Norway, 1410 skiing injuries were recorded from December 1990 through the 1996 season. In Hafjell, 183 of these injuries were plotted on an area map during the two first seasons. Similarly, in Voss, 214 injuries were plotted on an area map for two seasons. During the last three seasons in Hafjell, 835 ski injuries were related to 6712 snow grooming hours and 6 829 084 lift journeys.**Results:** The mean injury rate was 2.2 injuries per 1000 skier days, and the mean injury severity score (ISS) was 3.1. Accumulations of injuries at three sites (black spots) were recorded on the Hafjell area map. These injuries represented 40% of all injuries in the alpine area ( $p < 0.05$ ). Seven injury accumulation sites were recorded on the alpine area map of Voss, representing 22% of the total injuries ( $p > 0.05$ ). Grooming of the slopes was rated poor for the 49% of injuries that occurred at the sites of injury concentration and significantly different (27%) from injuries that occurred at random in Hafjell. The corresponding values in Voss were 50% and 25% respectively. Grooming hours appeared to be inversely proportional to the number of injuries:  $R = -0.99$  ( $p < 0.02$ ). The mean ISS declined significantly in Hafjell over the observation period ( $p < 0.001$ ).**Conclusion:** Inappropriate trail design and slope grooming seem to result in an accumulation of injuries at certain sites. Modification in construction and maintenance of the courses may reduce the number of injuries and mean ISS.

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Different elements of risk of a skiing injury have been carefully examined.<sup>1–10</sup> Recommendations are made for beginners to attend ski schools, and children and adolescents to use protective helmets and to perform self release tests of the binding every day before skiing.<sup>11</sup> Techniques for falling have been developed to prevent knee injuries.<sup>12</sup>

The use of the injury severity score (ISS) to classify skiing injuries in an alpine area has been useful.<sup>13–14</sup> Thus severe or critical injuries ( $ISS \geq 16$ ) may occur if something unexpected is encountered on the slope—for example, a net, a grooming machine, or a root. Potentially severe injuries ( $ISS 4–15$ ) are often suffered by beginners and may be concentrated at certain sites on the slopes,<sup>13</sup> called “black spots”. The term black spots is also used for traffic accidents.<sup>15</sup>

Little has been written about ski trail design and grooming of the slopes, but it has been proposed that better slope preparation would decrease injury risk.<sup>6–14–16</sup> Lystad<sup>17</sup> has reported a decrease in collision injuries after the number of trails had been increased and some widened in Hemsedal, Norway.

The purpose of this study was to evaluate the effect of trail design and grooming on the incidence of ski injuries, injury rate, and the mean ISS in two alpine ski areas.

**MATERIALS AND METHODS**

From 15 December 1990 through 15 April 1996, details of 1410 ski injuries were collected on forms designed to allow injury occurrence to be plotted on separate area maps from two different ski areas in Norway. In Hafjell, the ski patrol plotted 183 of these injuries on an area map from 15 December 1990 through 15 April 1992. To extend these findings, the ski patrol in Voss plotted 214 of the injuries on the area map from 15 December 1993 through 15 April 1995. The snow conditions on the slopes were classified as

good, poor, or not groomed on the same forms as the injuries. Of the remaining 1013 injuries in Hafjell (table 1), 835 from the 1994, 1995, and 1996 seasons were related to 6712 effective grooming hours with snow grooming machines and 6 829 084 lift journeys. Artificial snow makers were installed in Hafjell from the beginning, and snowmaking evened out some of the differences in conditions between the warmer and colder months and seasons.

All skiing injuries were related to age, sex, injury severity, and equipment used. A skiing injury was defined as an injury to a skier or snowboarder that required transportation or treatment by the ski patrol with an ISS of 1–75.<sup>13–18–19</sup> Twenty lift journeys were defined as a skier day. The injury rate was calculated from the total number of lift journeys and the total number of injuries every season.<sup>13</sup>

The ISS is derived from the anatomically based abbreviated injury scale (AIS).<sup>18</sup> Baker *et al*<sup>19</sup> used a mathematically derived code number by adding the square of the highest AIS code in each of the three most severely injured body regions:

$$ISS = AIS_1^2 + AIS_2^2 + AIS_3^2$$

where  $AIS_1$ ,  $AIS_2$ , and  $AIS_3$  are the body regions.

The doctor connected to both alpine areas calculated the ISS. Mean ISS was calculated for every season as the total ISS or sum of ISSs divided by the number of injuries in each alpine area, as reported previously.<sup>13–14</sup>

The results are presented as percentage of the injuries, injury rate, total ISS, and mean ISS.<sup>13</sup>

**Statistical analysis**

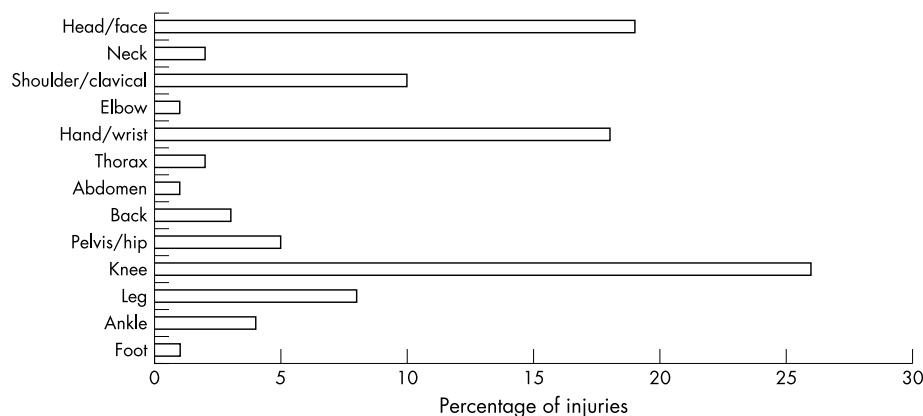
Distribution of injuries accumulated at certain sites or at random was tested by Student's *t* test. Pearson's correlation coefficient (*R*) was used to find any correlation between the total number of injuries and lift journeys, between injury rate

**Abbreviations:** AIS, abbreviated injury scale; ISS, injury severity score

**Table 1** Grooming hours, injury rate, and injury severity score (ISS) in Hafjell alpine ski area from 1991 through 1996

	Lift journeys	Number of injuries	Grooming hours*	Injury rate per 1000 skier days	Total ISS	Mean ISS per year
1991	770672	86		2.2	318	3.7
1992	1273812	97		1.5	337	3.6
1993	1709767	178		2.1	552	3.1
1994	2189764	243	2567	2.2	680	2.8
1995	2321446	280	2233	2.4	674	2.8
1996	2317874	312	1912	2.7	780	2.5

\*The exact number of grooming hours was not recorded in the period 1991–1993.



**Figure 1** Locations of skiing injuries in Hafjell and Voss over the period 1990–1996.

and lift journeys, between total number of injuries and grooming hours, and between injury rate and grooming hours in Hafjell. Multiple linear regression analysis was used when calculating how the numbers of lift journeys and the numbers of snow grooming hours influenced the numbers of injuries:

$$Y_i = a + bX_i + cZ_i + \epsilon_i$$

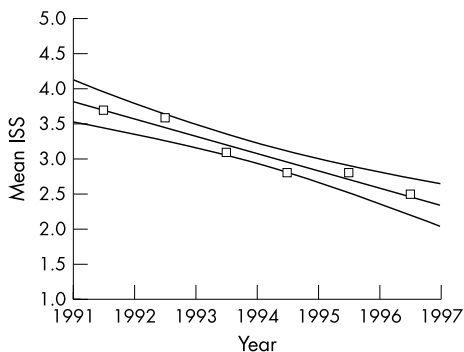
where  $Y_i$  is injury,  $X_i$  is lift journeys, and  $Z_i$  is snow grooming hours.<sup>20</sup> The significance level was  $p \leq 0.05$ . Linear regression was also used for analysis of the mean ISS throughout the period of observation. SPSS release 6.0, 1993 was used for the calculations.

**RESULTS**

**Injury related factors**

**Type, location, and severity of Injury**

The mean injury rate was 2.2 injuries per 1000 skier days. The mean ISS was 3.1 for the 1410 injuries, and 36% of injuries resulted in admittance to hospital.



**Figure 2** Mean injury severity score (ISS) for the injuries in the Hafjell alpine ski area 1990–1996. A significant reduction is observed ( $p < 0.001$ ).

Table 1 presents information on the number of injuries, injury rates, grooming hours, lift journeys, total ISS, and mean ISS during six winter seasons in Hafjell. In Voss 214 injuries were plotted on the alpine area map; the injury rate was 2.4 injuries per 1000 skier days, and the mean ISS was 3.0 per injury.

No significant differences in type of injury (table 2), location of injury (fig 1), injury rates, mean ISS, or numbers admitted to hospital were recorded between the two alpine areas, and the data are therefore combined. The injury distribution (percentage) in alpine skiing/snowboarding changed from 80/5 to 70/20 over the period of observation, with a mean value of 74/13 ( $p < 0.05$ ). Most of the injuries (57%) were contusions and sprains (table 2). About 26% of the injuries involved the knee (fig 1). A trend towards more injuries to the upper body became obvious in the last year of the records in Hafjell, and a small increase in ankle fractures was recorded in Voss. The mean ISS was calculated in Hafjell every season; it decreased from 3.7 to 2.5 over the period of observation (fig 2),  $R^2 = 0.97$  ( $p < 0.001$ ). A similar reduction in mean injury severity was not observed for snowboard injuries during this period.

**Table 2** Types of injury in the Hafjell and Voss alpine ski areas (n = 1410)

	Number	Percentage
Contusion	437	31
Sprain	367	26
Fracture	324	23
Open wound	155	11
Luxation	71	5
Other	56	4

**Table 3** Type of accident in the Hafjell and Voss alpine ski areas (n = 1410)

	Number	Percentage
Self induced fall	1128	80
Collision with another person	84	6
Collision at the edge of the slope	71	5
Lift accidents	56	4
Other	71	5

### Causes and mechanisms of injury

Self induced falls caused 80% of the accidents (table 3). Collisions with another person were recorded in only 6% of all injuries. At the black spots in Hafjell, however, collisions were recorded in 18% ( $p < 0.05$ ). Five percent of the injuries were recorded during off piste skiing, and injuries in ski lifts accounted for 4% of the total.

### Skier related factors

#### Age and sex

The injury distribution (percentage) among male/female skiers changed from 74/36 to 51/49 over the period of observation (1991–1996), with a mean value of 62/42 ( $p < 0.05$ ). About a third (35%) of the injuries occurred in 15–19 year olds (fig 3). In this age group some severe injuries to the head, neck, lower back, abdomen, and pelvis were recorded.

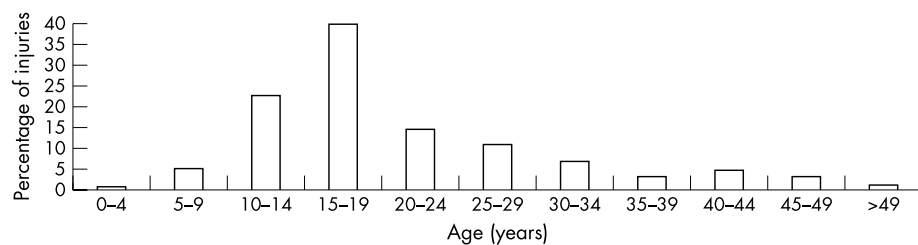
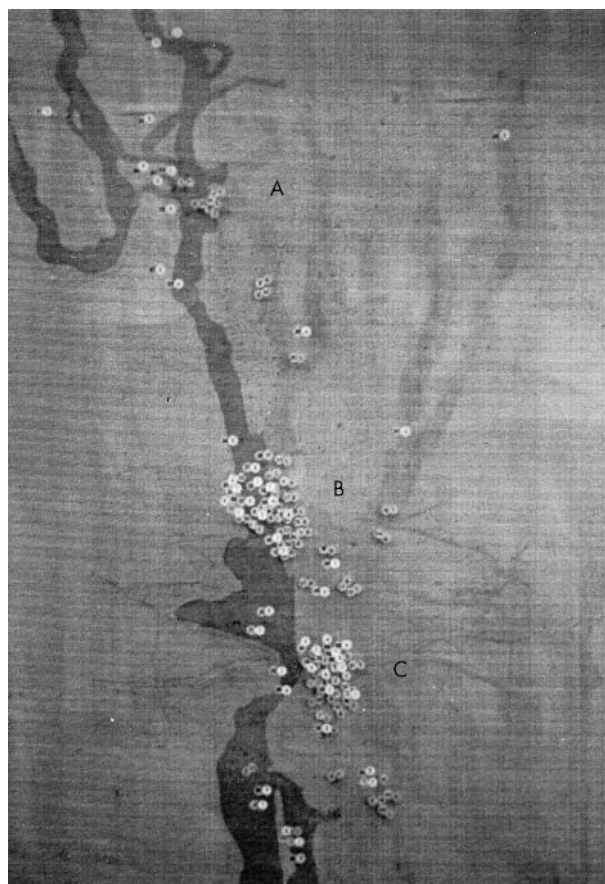
### Slope related factors

#### Architecture of slopes

A concentration of injuries occurred at three sites in Hafjell (fig 4). These black spots involved 40% of all injuries in the area ( $p < 0.05$ ).

The first injury accumulation (A) occurred where several slopes meet and continue downhill as one slope. The mechanisms of injury were either a collision or self induced fall. The second location (B) was the steep "Råbølhenget"; injuries were caused by skiers sliding out of control down the difficult course. At the third site (C), the slope had an hourglass shape from side to side and a small uphill part over a road tunnel where skiers, arriving at great speed from the "Råbølhenget", hit a compression and fell forward or backward. The seven injury populations in Voss also had their characteristics and injury mechanisms, but the incidence of injuries here did not differ significantly from those occurring at random.

Analysis of the data in table 1 showed that the injury rate decreased from 2.2 to 1.5 initially in relation to lift journeys (fig 5) when the slope was widened between the 1991 and 1992 seasons and a new slope for beginners was opened around the steepest part of the hill. The injury rate seemed to increase in relation to lift journeys after the flexible chair system started operating in the 1993 season (fig 5;  $p = 0.22$ ;  $R^2 = 0.34$ ).

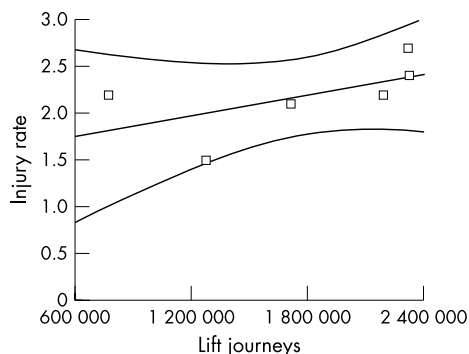
**Figure 3** Age distribution of 1410 skiing injuries 1990–1996 in two alpine ski areas in Norway.**Figure 4** Architecture of the slopes and concentration of injuries at three locations in Hafjell, marked A, B, and C.

### Grooming of slopes

Most of the injuries occurred on well prepared slopes (fig 6). However, the slopes were rated as partly or not groomed for the 49% of injuries that occurred at the black spots and for 27% of the injuries that occurred at random in Hafjell ( $p < 0.05$ ). The corresponding values in Voss were 50% and 25% ( $p < 0.05$ ).

The injury rate related to grooming hours (fig 7) seemed to increase steadily as the number of grooming hours was reduced over the observation period ( $p = 0.08$ ;  $R^2 = 0.98$ ). The correlation between the number of injuries and lift journeys was,  $R = 0.98$  ( $p < 0.02$ ). A significant negative correlation was found between the number of injuries and grooming hours,  $R = -0.99$  ( $p < 0.02$ ).

On running a multiple regression analysis using injuries as the dependent variable, two equations were created: (a) between injuries and lift journeys giving a significant correlation,  $R^2 = 0.98$  ( $p < 0.02$ ); (b) between injuries and grooming hours giving a significant correlation,  $R^2 = 0.99$  ( $p < 0.02$ ).



**Figure 5** Injury rate as a function of lift journeys was reduced after widening of the slopes and opening of a new slope for beginners in the second season of the observation period. The injury rate increased steadily when the flexible chair system started operating in 1993, transporting more skiers to the slopes.

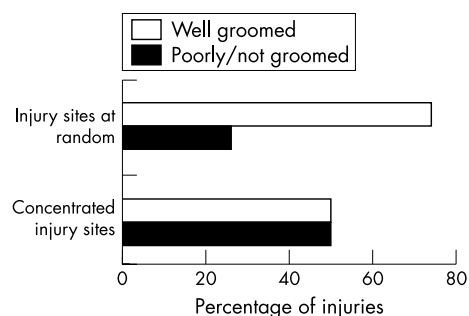
## DISCUSSION

Alpine skiing was the most popular activity at the two alpine areas, and snowboarding was a growing trend. Only small differences in types of injury and accidents were recorded between the two areas. Injuries to the knees were most common, but the incidence of these injuries seemed to remain stable during the period of observation (fig 1), and were similar to other reports from Norway.<sup>21 22</sup>

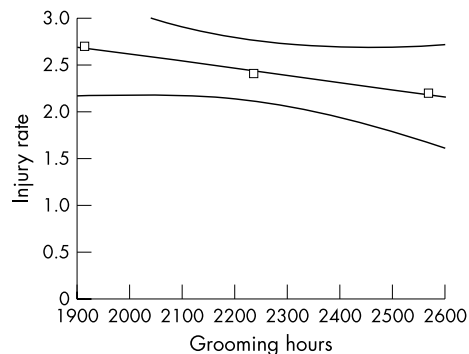
The injury rate decreased initially from the 1991 season to the 1992 season (table 1, fig 5) in accord with better safety measures on the slopes. Some of the courses were broadened, and the roughness of the slopes was repaired, particularly at the edges<sup>13 14 17</sup>. Over the last few years of the study period (table 1, fig 5), the injury rate seemed to increase after the flexible chair system started operating in 1993. The capacity of the chair lifts in Hafjell was doubled without being offset by new runs. Corresponding findings have been reported by Lystad<sup>17</sup> for Hemsedal and by Young and Lee<sup>23</sup> for the Waterville ski area of New Hampshire, possibly the result of concentration of skiers on the slopes.

The mean ISS value decreased significantly over the period of observation (fig 2). This can be related to more careful recording of the injuries, with more injuries coded as ISS = 1, but it can also be related to precautions taken and better safety standards on the slopes, so that the severe injuries coded ISS $\geq$ 16 were avoided.<sup>13 14</sup>

Figure 3 shows that most of the injured skiers were aged 15–19 years in both alpine areas. Ekeland *et al*<sup>8</sup> have previously reported this age group to be at greatest risk of ski injury.



**Figure 6** Occurrence of injuries at concentrated sites (black spots) or at random on the alpine ski slopes of Hafjell and Voss. At the black spots, more of the injuries occurred on poorly groomed or ungroomed slopes in contrast with the injuries occurring at random ( $p < 0.05$ ).



**Figure 7** Injury rate as a function of grooming hours on the alpine ski slopes of Hafjell.

There are two important findings from this study to be discussed:

- (1) the architecture of the slopes in relation to injury black spots
- (2) injury incidence in relation to machine grooming hours in the Hafjell alpine ski area.

After plotting of injuries on the maps for two years, we found areas of injury concentration that certain slope designs may increase the risk of injuries. The injuries concentrated at three sites on the slopes (fig 4, marked A, B, and C) made up 40% of all the injuries in Hafjell. This concentration of injuries was significant compared with injuries occurring at random on the slopes of Hafjell. The trail designs at these black spots have been described previously, and notices asking skiers to slow down should be posted where two slopes merge into one. It is also important to avoid narrow passages in a slope and provide easier bypasses for beginners.

Most of the injuries occurred on well groomed courses (fig 6), but the snow conditions on the black spots were poor or ungroomed in about 50% of the skiing accidents and differed significantly from the snow where the injuries occurred at random in both alpine areas. We think that these black spots were at cross points in the terrain. The surface may have been steep or the ground uneven causing the surface of the snow to wear out easily and became loose and undulating, sometimes hard and icy. The incidence of injuries caused by collisions was also significantly higher at these locations. These findings may suggest a connection between slope grooming and the number of injuries, as mentioned by Matter *et al*<sup>16</sup> and later by Lystad.<sup>17</sup>

We can see from table 1 and fig 7 that in the 1994, 1995, and 1996 seasons in Hafjell both the number of injuries and the injury rate were increasing as the number of grooming hours were reduced, and that these findings are very close to a straight line. By analysing these data by Pearson correlation, the number of hours of grooming with machines seemed to be inversely proportional to the number of injuries ( $p < 0.02$ ).

A significant correlation was also found between the number of injuries and the number of lift journeys ( $p < 0.02$ ), but it is expected that the total number of injuries increases as more skiers enter the slopes.

Thus, the effects of trail design and grooming on the incidence of injuries at alpine ski areas are important considerations, but further records are needed over a longer period to confirm these findings. Unfortunately, there is little comparative information in the literature. Matter *et al*<sup>16</sup> refer to new methods of planning and preparation of ski runs as one of the reasons for the reduced injury incidence in the

## Take home message

By using a ski area map to locate injury black spots, the design of the slopes can be improved. Satisfactory grooming of the snow, particularly at injury black spots, may reduce the mean ISS and the number of injuries.

Davos area. Lystad<sup>17</sup> reported that wider slopes in Hemsedal in Norway reduced the "collision zone" at the three slope border and resulted in safer skiing on each slope.

Penniman<sup>24</sup> has proposed safety standards for the construction and maintenance of trails in skiing areas in the United States. Safe trail configurations and maintenance are put forward as the most important precautions in his skiing safety hierarchy.

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