Results of a survey on the risk of ski cutting avalanches

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Abstract

In avalanche operations, ski cutting involves a single avalanche practitioner attempting to trigger a snow avalanche by skiing across the upper part of a slope. There are two types of ski cutting: *test skiing* to determine if the snow is unstable and *mitigation* to remove unstable snow before the avalanches get bigger or before less skilled people (e.g. clients) travel on or below the specific slopes. To address the wide differences in the perceived risk of injury during ski cutting, we conducted a quantitative survey that helped avalanche practitioners estimate the number of ski cuts over many winters and asked them to recall their near misses and three classes of injuries. Over 150 practitioners completed the survey with a combined career total of 1.5 million ski cuts. From the responses, we calculated various results. The median number of ski cuts per respondent is 300 per winter. The rate of triggering a size D1 to 1.5, D2 to 2.5 and D3+ avalanche was 300, 4 and 0.1 per thousand ski cuts, respectively, indicating that smaller avalanches are triggered much more often than larger ones. The rate of being caught in a size D1 to 1.5, D2 to 2.5 and D3+ per thousand triggered avalanches was 7, 25 and 80, respectively, indicating that the probability of being caught increases with the size of an avalanche triggered during ski cutting. When the survey results are scaled to a million ski cuts, about 23 resulted in light duty, 7 resulted in missed work and 3 resulted in career ending injuries. Practitioners at lift-based ski areas (ski patrollers) had lower risk for the same number of ski cuts than guides for helicopter and snowcat skiing. The survey responses covered approximately 40 years. Over this time, there was no clear increase or decrease in the rates of near misses or serious injuries per ski cut.

Highlights of this paper are presented in a video at https://vimeo.com/351249723.

1. Introduction

A ski cut is an attempt to trigger an avalanche by starting in a low risk location, skiing across all or part of an avalanche start zone to a location with lower risk. This study does not distinguish between slope cutting on skis or a snowboard.

Figure 1: A small dry slab avalanche triggered by a ski cut. B. Jamieson photo.

Ski cutting is a basic skill that remains widely used by avalanche practitioners. For example, one of the competencies in the Canadian Avalanche Association's 2015 draft competency profile is "artificial triggering (excluding the use of explosives)". Some winter recreationists also ski cut slopes, but the survey and this paper pertain exclusively to ski cutting by avalanche practitioners while at work.

There are two types of ski cutting: *test skiing* to determine if the snow is unstable and avalanche hazard *mitigation* to remove unstable snow before the avalanches get bigger or before less skilled people (e.g. clients) travel on or under the specific slopes. Looking at avalanche operations across North America, the number of slopes ski cut for mitigation in a winter far exceeds the number of slopes test skied.

Advantages of ski cutting:

- Provides high strength and high weight evidence of snow instability, which is key information for avalanche forecasting operations. Many slopes ski cut but not triggered is an indicator of stability and can be of high weight if many representative slopes are ski cut.
- Removes unstable snow before the avalanches get bigger during storms or before less skilled people (e.g. clients) get to the slopes.
- More effective for triggering for loose wet snow avalanches than explosives.
- Faster than explosives when dealing with many start zones if only small avalanches are expected.
- Can be efficiently used in combination with explosive mitigation, i.e. ski cutting for the smaller or less severe slopes and explosives for the more severe slopes. Also, practitioners can "clean up" (i.e. remove) small pockets of unstable snow that remain after explosive mitigation.
- Cost effective when there are many start zones and/or practitioners with related skills (e.g. guiding, first aid, skiing) who are consistently on site.
- Practitioners can learn about the spatial characteristics of unstable snow, i.e. trigger points which is relevant to placing explosives, as well as snowpack variations over terrain that are relevant to avalanche release and route selection. Practitioners can also learn about the transient nature of snow instability, including storm slabs. This knowledge about the spatial and temporal characteristics of unstable snow is difficult to learn in the classroom.

Disadvantages of ski cutting:

- People can be injured and potentially killed while ski cutting.

- For operations with many small slopes and a few large slopes (or slopes with terrain traps), the efficiency of ski cutting can deter the use of lower risk methods of avalanche mitigation, such as explosives, on the larger or more serious slopes.
- The distinction between a low risk ski cut and a high risk ski cut can be difficult to consistently determine in advance (e.g. on a day when ski cutting many shallow slabs resulting in D1 avalanches, practitioners infrequently trigger slabs that are deeper than expected, resulting in larger avalanches).
- A small number of ski cuts that do not trigger avalanches can be misleading, i.e. they do not provide high weight evidence of stability, especially for deeper weak layers.

The perception of the risk of injury and death during ski cutting varies widely. Discussions between "avoiders" (who perceive the risk to be unacceptably high) and "engagers" (who perceive the risk to be low and acceptable) are frequently unsatisfactory.

The objectives of this study are:

- To quantitatively estimate the rate of near misses and injuries from ski cutting and hence inform policies, practices, decisions and discussions about ski cutting
- To quantitively estimate the rate of triggering and being caught while ski cutting by avalanche size (Table 1)
- To inform policies, practices and decisions about ski cutting by practitioners, and
- To improve discussions between avoiders and engagers with quantitative data on the risk of ski cutting.

Table 1: Classes of avalanche size by destructive potential (McClung and Schaerer, 2006, p. 322)

Size[a]	Destructive potential	Typical mass (t)	Typical path length (m)
D1	Relatively harmless to people.	< 10	10
D2	Could bury, injure or kill a person.	10^2	100
D3	Could bury a car, destroy a small building, or break a few trees.	10^3	1000
D4	Could destroy a railway car, large truck, several buildings, or a forest with an area up to 4 ha.	10^4	2000
D5	Largest snow avalanches known; could destroy a village or a forest of 40 ha.	10^5	3000
[a] the D prefixing the number is a recent addition to distinguish this classification of destructive potential from other numerical avalanche size classifications. Experienced practitioners may use half sizes, 1.5 to 4.5, for avalanches that are halfway between defined size classes.			

The survey and this paper do not identify practices to minimize risk while ski cutting. However, Stimberis (2008, 2018) and Wilbour (1986) identify low risk practices for ski cutting. Also, Richmond (1994) and Vesely (2014) identify patterns in near misses and injurious ski cuts.

A brief history of ski cutting

In this section, we review ski cutting as mentioned in selected publications, especially older publications. Where multiple editions of a publication were available on our bookshelves, we used the oldest edition.

Seligman (1936, p. 483) mentioned triggering unstable snow (mitigation) by sending a belayed skier onto the slope. In a chapter of the NRC/BCIT manual for Canadian avalanche practitioners, Wilson (1974) outlines test skiing as well as "protective skiing" (i.e. mitigation) before more unstable snow accumulates or hours before naturals are expected. Perla and Martinelli (1976, p. 104) noted that unbelayed test skiing should be on small slopes only, implying belayed test skiing is an option for bigger slopes. LaChapelle (1970) outlined test skiing on short slopes. The Canadian Avalanche Association's (CAA) 1985 curriculum document for courses for advanced recreationists specifies that the instructor "demonstrate test skiing" and twice mentions that recreationists should consider the results of test skiing when assessing the avalanche hazard. When describing test skiing for winter recreationists, Daffern (1992, p. 144) recommends caution on larger slopes. Hence, ski cutting (test skiing and mitigation) has a long history for avalanche practitioners and winter recreationists.

Fatalities during ski cutting in the United States and Canada

Since 1980, there have been three fatalities associated with ski cutting in the U.S. according to records maintained by the Colorado Avalanche Information Center. The first fatality was a person who ski cut a large avalanche after explosives had been thrown on the slope in 1983. This was in an out-of-bounds area that was not normally skied or mitigated for avalanche hazard, and a wide avalanche released in depth hoar near the ground. The second fatality was in 1994 and involved a patroller ski cutting a slope at the end of their control route when they had run out of explosives. The third ski cutting fatality was in 2016 and involved a cat skiing guide who was ski cutting some terrain before opening it for his guests.

Also since 1980 in the U.S., there have been nine avalanche fatalities in seven incidents during explosive mitigation of avalanches. In each one of these cases the avalanche mitigation team threw an explosive downhill of their position, but the resultant avalanche propagated upslope, capturing the practitioner(s). While these accidents are not a completely valid comparison with ski cutting since explosives are preferred over ski cutting for larger slopes and deeper slabs, these fatalities demonstrate that explosive control is not a risk free alternative to ski cutting.

According to records kept by the Canadian Avalanche Association and more recently by Avalanche Canada, there has only be one avalanche fatality during ski cutting in Canada. In this 1994 incident, the rescue of the buried practitioner was delayed because he was not wearing an avalanche transceiver (Jamieson and Geldsetzer, 1996, p. 94-95).

2. The Survey

The links to the introductory video and the survey were sent to avalanche practitioners through a variety of associations in the US, Canada and New Zealand.

The survey was anonymous and intended only for avalanche practitioners. No demographics were collected but the start date and number of winters in each phase of a practitioner's career were required.

The wording in the survey discouraged potential respondents who did limited ski cutting, e.g. "How many winters during this career phase did you ski cut many slopes, say 20+ slopes per winter? (If there are no such winters in your career, thank you for your interest in the survey.)" Hence, avalanche practitioners who do limited ski cutting are likely underrepresented in the results.

The survey distinguished between five types of avalanche work (sectors): Lift-based ski areas (i.e. ski patrolling), mechanized ski guiding (for helicopter and snowcat skiing), non-mechanized ski guiding (for ski touring), highways and resource industries, backcountry forecasting (for public avalanche warnings), and a category for other types of avalanche work.

Each respondent could estimate their ski cuts and injuries for one or two career phases in which they did the most ski cutting. Each career phase was for one or more winters in a specified sector. For each career phase, respondents were asked to recall and estimate their average number of ski cuts per winter, number of winters, as well as the number of their near misses and injuries.

As is common for analyzing the risk to workers, respondents were asked about four types of events:

A *near miss* is an unplanned event that did not result in injury, illness, or damage, but had the potential to do so. Some respondents may not consider being caught in a D1 avalanche to be a near miss since such avalanches are, by definition, relatively harmless. Also, loose wet avalanches reliably start at – not above – the practitioner's skis although these avalanches may entrain considerable snow while descending. Hence, some respondents may not consider larger loose wet avalanches, e.g. Size D2, to be near misses.

Light duty refers to a period of one or more days of paid work in which the injured worker does work that is physically less demanding, e.g. office work.

Missed work refers to a period of one or more days in which the injured worker is unemployed. The injured worker may receive some financial compensation but is not employed to perform their regular or light duties.

End of career typically refers to a career ending injury. Since the survey allows for a second career phase, e.g. forecasting for a highways avalanche program after a career phase as a ski patroller, this type of injury is referred to as *end of career phase*.

3. Analytical methods

When planning the analysis, we originally intended to focus on the median rate of injuries per respondent (i.e. second quartile, Q2) as well as the first and third quartile (Q1, Q3). However, less than 50% of the respondents had been injured, so the medians per respondent for all types of injuries were zero. Therefore, we switched to our focus to the average rate of injuries per ski cut for all respondents (e.g. total number of injuries / total number of ski cuts). This approach has the advantage that all responses were included. However, the average rate per ski cut is influenced by extreme values, including outliers. During preliminary analysis (not shown), we plotted the data so potential outliers would be obvious. One respondent reported ski cutting on more than 365 days per winter. This may have been due to misinterpretation of a question or a typo; nevertheless, we excluded this respondent's record. Another respondent reported an injury rate 32 times the second highest injury rate. This record was also excluded, although we are unsure if the respondent misunderstood a question, made a typo or, indeed, had a very high injury rate. Another respondent reported a near miss rate three times the second highest near miss rate. This respondent's record was retained.

Where the rates of near misses or injuries in this study are based on large representative samples, they can be considered average probabilities for the US, Canada and New Zealand and used for preliminary risk calculations.

To improve risk communication, frequencies are preferred to single event probabilities (e.g. Gigerenzer and Edwards, 2003). Since many of the probabilities in this study are small numbers, e.g. $3x10^{-4}$ per ski cut, we report most frequencies as *n* events per million ski cuts.

4. Results and discussion

There were 163 complete responses, but two responses were excluded as noted above. Fifty of the respondents had complete answers for a second career phase, giving a total of 161 + 50 = 211 career phases of data for analysis. The career phases ranged in length from 1 to 38 winters with an average of 11 and a median of 9 winters.

Number of ski cuts per winter per respondent for the various sectors

Table 2 shows the number of career phases and number of ski cuts per winter and total for the different sectors. To our knowledge, the number of ski cuts winter for avalanche practitioners has not been previously reported.

Table 2: Number of ski cuts per winter per respondent and total by sector

Sector	No. of career phases (all respondents)	No. of ski cuts (all respondents)	No. of ski cuts per winter per respondent			
			Q1	Q2 (Med.)	Q3	Average
Ski areas	128	1,081,962	199	400	810	661
Mechanized ski guiding	45	323,905	120	300	700	476
Non-mechanized ski guiding	15	11,189	63	90	158	108
Highways & resource industry	9	59,140	60	78	660	428
Backcountry forecasting	11	14,245	40	140	233	191
Other	3	5,380	40	60	130	93
All sectors	**211**	**1,495,821**	**120**	**300**	**700**	**539**

The sectors for non-mechanized ski cutting, highways and resource industries, backcountry forecasting and other each represent less than 16 career phases (Table 2). To avoid questionable inferences or conclusions regarding the sectors with limited data, the results for these sectors are excluded from subsequent analyses. Consequently, our analysis focused on ski areas (128 career phases) and ski guiding (45 career phases).

Triggering rate by avalanche size and sector

Figure 2 and Table 3 show that the triggering rate per million ski cuts decreases sharply with increasing avalanche size. When looking at the data for all sectors, about 35% of ski cuts result in avalanches that are D1-1.5 in size, with only 0.4% resulting in D2-2.5 size avalanches and only 0.014% resulting in size D3+ avalanches.

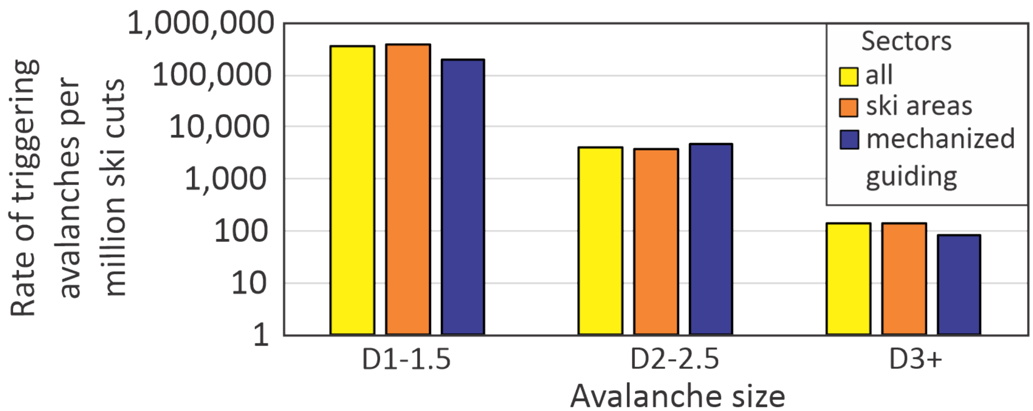

Figure 2: Rate of triggered avalanches per million ski cuts by avalanche size and sector. The log scale for the left axis allows the triggering rate for D2 to 2.5 to be distinguished from the rate for size D3+ avalanches.

For Size D1 to 1.5 and D3+ avalanches, ski area practitioners reported a triggering rate about twice as high as ski guides (Table 3). For size D2 to 2.5 avalanches, the triggering rate is about 25% higher for ski guides than for ski area practitioners (ski patrollers).

Table 3: Triggering rate per million ski cuts by avalanche size

Sector	Avalanche size		
	D1-1.5	**D2-2.5**	**D3+**
All	345,056	4,038	143
Ski areas	394,442	3,760	141
Mechanized guiding	196,212	4,677	86

Probability of being caught in a triggered avalanche during ski cutting by avalanche size and sector

Table 4 and Figure 3 show that the probability of being caught in an avalanche triggered during ski cutting increases with the size of the triggered avalanche. There is little consistent difference in the rate of being caught between mechanized ski guiding and ski areas. Note that size D1 avalanches are considered relatively harmless (Table 1).

Table 4: Rate of being caught per million triggered avalanches by avalanche size

Sector	Avalanche size		
	D1-1.5	**D2-2.5**	**D3+**
All	7,436	24,665	79,439
Ski areas	6,359	26,549	91,503
Mechanized guiding	9,693	17,162	107,143

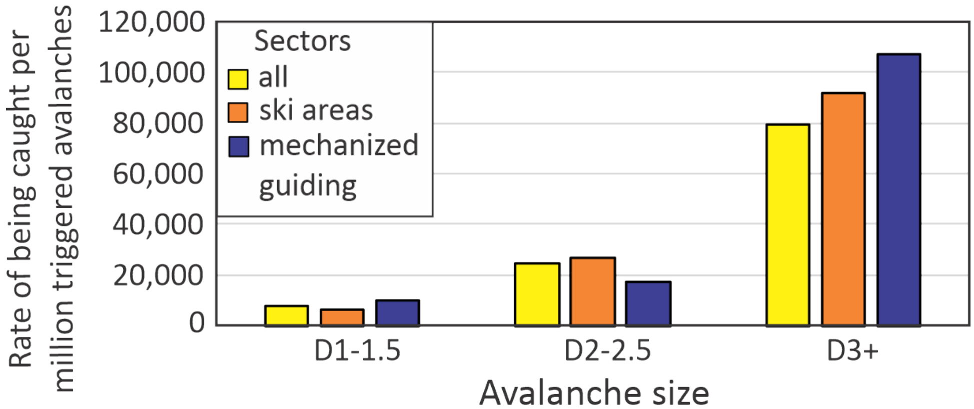

Figure 3: Rate of being caught per million avalanches triggered while ski cutting for three size classes of avalanches (D1-1.5, D2-2.5, D3+). The results are shown for ski areas, for mechanized ski guiding, and for all sectors.

Risk to practitioners: Near miss and injury rates from ski cutting

The number of reported near misses and injuries for ski areas and mechanized guiding are presented in Table 5. Only 7 and 4 injuries resulted in missed work, or ended career phases, respectively, so interpretations and extrapolations based on such limited data for serious injuries should be made with caution.

Table 5: Summary of survey responses including near misses and injuries by sector

Sector	No. of career phases	No. of ski cuts	Number of near misses and injuries			
			Near miss	Light duty	Missed work	End career phase
Ski areas	128	1,081,962	444	19	3	1
Mechanized ski guiding	45	323,905	106	12	4	3

Figure 4 shows that the injury rate for mechanized ski guides per million ski cuts is approximately two and a half times the rate for ski area practitioners. This is may be due to:

- Ski area practitioners having better options for explosive use on more serious slopes or when the slabs are thicker,
- The slopes that ski area practitioners ski cut are often more ski compacted, reducing the frequency of deeper than expected avalanches,
- The technique – including start and stop locations – for specific slopes are more often pre-established and mentored for ski areas,
- The history of specific slopes and ski cuts is better documented at ski areas allowing for more informed slope-specific decisions, and
- Ski area practitioners may have a long prescribed list of slopes to ski cut when there is a small accumulation of new snow overnight, e.g. 5 cm (i.e. when the risk is very low).

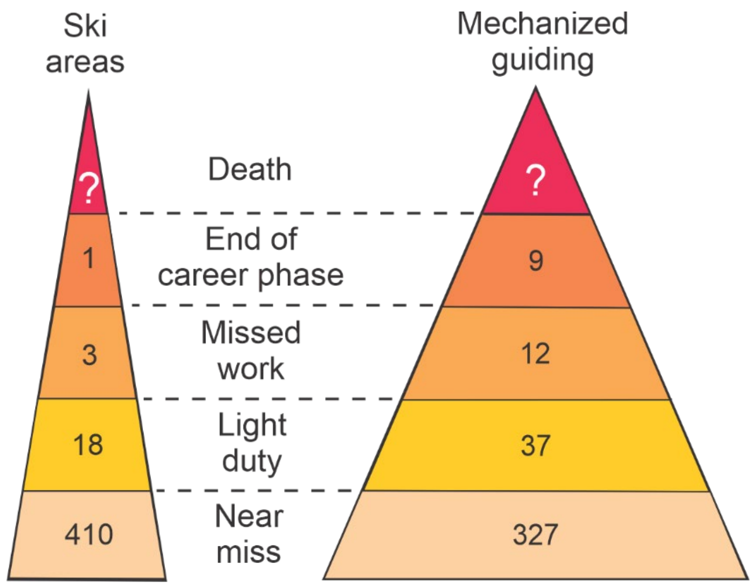

Figure 4: Risk (rate of near misses and injuries) per million ski cuts for ski areas and mechanized guiding. The bases of the triangles are scaled by the total injury rate (excluding near misses) for the sector as shown in Table 5.

For ski areas and mechanized ski guiding, the frequency or rate of near misses and injuries *per winter* can be estimated from Table 5 and the estimated number of ski cuts per winter in Table 2. However, the reciprocal of average frequency, i.e. average number of winters per near miss or injury, is a more intuitive way of comparing infrequent events. Table 6 and Figure 5 show the average winters per near miss or injury for the two sectors with the most data.

Table 6 shows that the average winters per event increases with the seriousness of the injury. Also, the average winters per injury for mechanized ski guiding are fewer than for ski area practitioners because mechanized ski guides reported more frequent injuries than ski area practitioners.

Table 6: Average number of winters per near miss or injury for practitioners with the median number of ski cuts per winter from Table 2.

Sector	Near miss	Light duty	Missed work	End career phase
Ski areas	6	142	902	2,705
Mechanized guiding	10	90	270	360

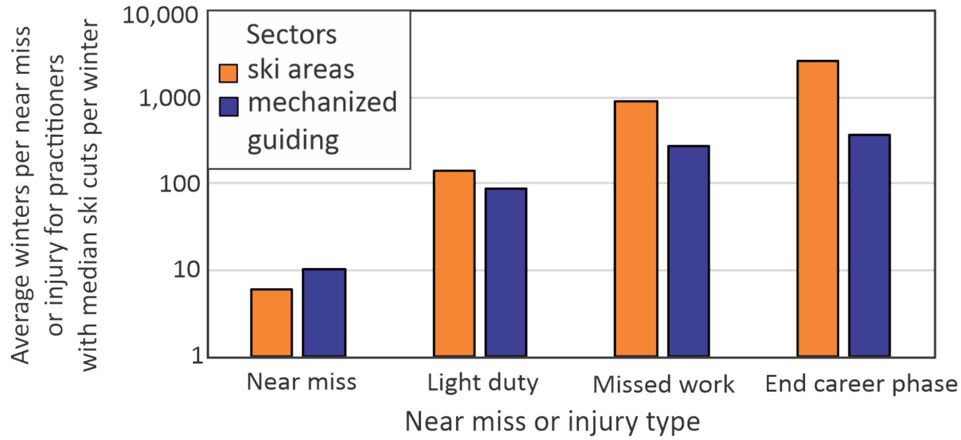

Figure 5: Estimated average number of winters per near miss or injury for practitioners with the median number of ski cuts. The left axis uses a log scale so that shorter columns, e.g. the average winters per near miss or light duty injury, are clearly displayed.

The average number of winters per injury *within an operation* can be roughly estimated by dividing the numbers in Table 6 by the typical number of practitioners engaged with ski cutting. For example, for an operation with 50 practitioners, the average winters per ski cutting injury resulting in light duty would be 142/50 ≈ 3 years for a ski area and 90/50 ≈ 2 years for a mechanized guiding operation. Avalanche operations can use this approach to check if their rate of near misses and injuries are roughly comparable to those in this study. However, the duration of near miss and injury records should preferably be at least three times as long as the average number of winters per near miss or injury in the comparison, (i.e. an average of 10 winters per near miss is best assessed over 30 or more winters).

Trends in ski cutting risk over time by sector

For each career phase, each respondent provided the start winter and the number of winters. From these data we calculated a middle winter for each career phase. To assess whether the rate of near misses or injuries was increasing or decreasing over time, we calculated the rate of near misses and injuries for three intervals: 1980-1999 (middle winters of 20 career phases), 2000-2009 (middle winters of 64 career phases) and 2010-2019 (middle winters of 121 career phases). Because of limited data before 2000, the first interval is twice as long as the latter two intervals. The results are shown in Table 7 and Figure 6.

Table 7: Rates of near misses and injuries over time per million ski cuts

Middle winter	No. of winters	Ski cuts	Near miss/10	Light duty	Missed work	End of career phase	All injuries
1980-1999	20	39,922	41.5	0.0	8.0	0.0	8.0
2000-2009	64	128,387	33.4	15.6	6.2	3.1	25.0
2010-2019	121	243,770	46.4	32.9	6.9	2.7	42.5

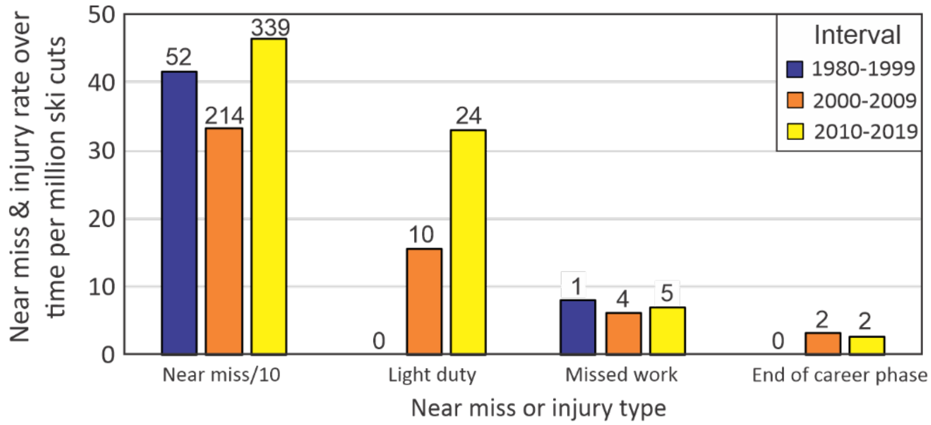

Figure 6: Rate of near misses/10 and injuries over time per million ski cuts for three types of injury (light duty, missed work, end of career phase) for three intervals. The first interval spans 20 winters whereas the second two intervals each span 10 winters. The number of near misses per million ski cuts was divided by 10 (i.e. near misses per 10 million ski cuts) to better display the columns for the infrequent injuries, i.e. missed work and end of career phase. The number above each column is the total number of near misses or injuries in the interval. The number is not proportional to column height, which is scaled by the number of ski cuts in the interval.

Figure 6 does not show a trend in the rate of near misses or injuries resulting in missed work. Also, we do not interpret a trend in injuries that ended a career phases since this would be based on 0, 2, 2 career ending injuries for the three time intervals, respectively. However, Figure 6 indicates an increase over time in the rate of injuries that resulted in light duty. This could be due to less recollection of early light-duty injuries from decades ago (i.e. not a real trend) but then the same trend would be expected for near misses, which are even less memorable. However, the trend could be due to the increased efforts of employers to track minor injuries, leading to better recollection by practitioners. Overall, we do not see convincing evidence of a trend in the rate of injuries.

Given the limited data for the rate of Missed work and End of career phase injuries, we did not look for trends in the sectors for ski areas and mechanized guiding.

Discussion on the probability of being killed in an avalanche while ski cutting

This survey relied on each respondent's recollection and hence yielded no data on deaths. However, the probability of a practitioner being killed in an avalanche while ski cutting can be estimated based on U.S. data for the last 40 winters. Greene et al. (2014) estimated that there are about 2780 avalanche practitioners in the United States. Assuming two thirds of these practitioners ski cut the average number of slopes per winter (Table 2), then there are about one million ski cuts per winter in the United States, i.e. about 40 million ski cuts over the last 40 years. Since three practitioners have died in avalanches while ski cutting in the U.S., this suggests a probability of death of about 0.08 per million ski cuts. Allowing for uncertainty in the number of ski cuts per winter of half an order of magnitude on either side of this estimate, the range in the probability of death is about 0.02 to 0.2 per million ski cuts.

There are physical reasons why the probability of death while ski cutting should be lower than other activities in avalanche terrain. Avalanche practitioners performing ski cutting will have a low vulnerability because they are more often caught on skis while high in the start zone (which reduces the avalanche mass and force on the practitioner), the ski cutting teams are skilled in companion rescue, and the ski cutting occurs within operations with good capability for organized avalanche rescue.

5. Recommendations

Due to improved worker regulations, risk management plans, etc. over the last three decades, we expected a decrease in the rate of injuries resulting in missed work and end of career phase injuries. Based on Table 7 and Figure 6, we are unsure if there is no trend, or if our survey missed a real trend. We recommend further study of the trend over time in the rate of ski cutting injuries.

We also recommend a study of the risk of ski cutting for the sectors with limited survey responses in this study, specifically non-mechanized ski guiding (for ski touring), highways & resource industries, and backcountry forecasting for public avalanche warnings.

While some avalanche operations have shared their ski cutting procedures, we recommend that procedures be widely shared within sectors so that best practices can be established and published.

We recommend that operations keep comprehensive records of ski cutting and any injuries so that recurring factors in near misses and injuries can be identified and mitigated.

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