Occupational Injuries in the Mining Industry and Their Association With Statewide Cold Ambient Temperatures in the USA

Juhani Hassi, MD,[1]* **Lytt Gardner** PhD,[2] **Scott Hendricks** MS,[2] and **Jennifer Bell** PhD[2]

Background *Relatively few occupational epidemiological studies have been conducted concerning the association between cold ambient temperatures and cold exposure injuries, and fewer still of traumatic occupational injuries and cold ambient temperatures.*

Methods *The association of ambient temperature and wind data from the National Climatic Data Center with injury data from mines reported to the Mine Safety and Health Administration (MSHA) was evaluated over a 6 year period from 1985–1990; 72,716 injuries from the seven states with the most numerous injuries were included. Temperature and wind data from each state's metropolitan weather stations were averaged for each day of the 6 year period. A weighted linear regression tested the relationship of ungrouped daily temperature and injury rate for all injury classes. For cold exposure injuries and fall injuries, relative incidence rates for grouped temperature data were fit with Poisson regression.*

Results *As temperatures decreased, injury rates increased for both cold exposure injuries and slip and fall injuries. The association of slip and fall injuries with temperature was inverse but not strictly linear. The strongest association appeared with temperatures 29° F and below. The injury rates for other accident categories increased with increasing ambient temperatures.*

Conclusion *This study suggests that statewide average ambient temperature reflects the expected association between the thermal environment and cold exposure injuries for workers, but more importantly, documents an association between ambient temperatures and occupational slip and fall injuries.* Am. J. Ind. Med. 38:49–58, 2000.
Published 2000 Wiley-Liss, Inc.†

KEY WORDS: cold exposure; slip and fall injuries; occupational injuries; Mine Safety and Health Administration data; environmental temperature

INTRODUCTION

Environmental cold causes health risks by reducing the temperature in the human body, in environmental surfaces, machines and tools at work places. The temperature reduction may cause functional alterations in machinery or work practices. These temperature reductions can be the principal or associated cause of acute injuries, diseases or increased symptoms in healthy and chronically ill workers.

As a consequence of direct or indirect effects of cold, the total injury rate may be changed in relation to environmental cold exposure. Causal relations between different injury sources and accident types, nature of injury and degree of disability from injury may have different pathways, too (see Fig. 1). The effect of cold on a worker is dependent on the circumstances where he works and what

[1]Finnish Institute of Occupational Health, Oulu, Finland
[2]Division of Safety Research, National Institute for Occupational Safety and Health, Cincinnati, Ohio
Contract grant sponsor: The Finnish Work Environment Fund; Grant number: 96115.
*Correspondance to: Juhani Hassi, MD, Finnish Institute of Occupational Health, Aapistie 1, 90220 Oulu, Finland. E-mail: juhani.hassi@occuphealth.fi

Accepted 7 January 2000

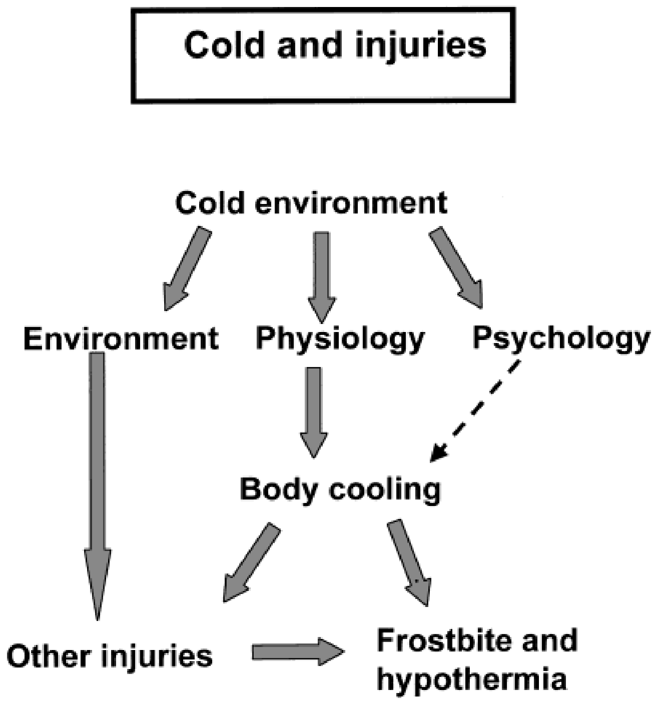

FIGURE 1. The relationship between cold and injuries.

kind of cold protection he uses. If the clothing or technical cold protection or other cold-associated arrangements at work are proper they can decrease the injury risk caused by cold exposure. The effect of cold exposure on an employee is work dependent: whether it is inside or outside a vehicle, whether it involves high metabolic heat production or not, and whether it imposes high demands of dexterity, especially in the hands.

The incidence rate of occupational injury was reported to have its minimum at a temperature of about +20°C and increasing in colder and warmer temperatures in the field studies carried out at projectile factories [Osborne and Vernon, 1922]. Ramsey et al. [1983] presented a U-shaped curve of the association between temperature and safety related behavior of workers in a metal product manufacturing plant and a foundry. The incidence of occupational injuries rose significantly when temperature was higher or below the seasonal average [Turk and Klinker, 1986]. Injury rates in British coal mines above the ground were 9% less numerous in the summer, while those below the ground were 7% more numerous in the summer [Vernon, 1936; Pekkarinen, 1994].

In recent years in the USA there have been very few publications concerning the association of traumatic occupational injuries with low ambient temperatures. On the other hand, there have been some reports of the association of ambient temperatures with injuries from direct thermal exposures. Occupational cold exposure injuries in the USA were reported by Jensen [1983] and Sinks et al. [1987] using Workers' Compensation claims. The Jensen study gives rough national estimates of the risk of thermal exposure injuries. The industries (2 digit SIC-code) with the largest incidence rates of cold exposure injuries were mining (10.2 injuries per 100,000 employees), agriculture (4.7 per 100,000), and transportation (4.6 per 100,000). The highest share of cold exposure injuries within industries were in electric, gas and sanitary services (8.1%), justice, public order and safety (6.0%) and food and kindred products (5.4%) [Jensen, 1983]. These injuries were more likely to occur during the winter months, November–March (84.5%). Winter injuries were associated with jobs requiring outdoor work. The most frequent injuries were frostbites (92%), which resulted mainly from cold exposure during outdoor routine work. The majority of the outdoor cold exposure injuries occurred during the coldest winter days, where an increased wind speed strongly increased the injury rate [Sinks et al., 1986].

We conducted this study to determine the nature of the association between occupational injuries and temperature, as well as to illuminate factors that influence the risk of injury during cold exposure. The purpose was to: 1) characterize the effect of environmental temperature and wind on injury rates; 2) characterize direct cold exposure injuries; 3) compare the distribution of circumstances by categories of the MSHA accident coding scheme; 4) analyze temperature dependence on different severity classes of injuries; and 5) characterize the amount of environmental cold exposure in the seven states.

MATERIAL AND METHODS

Study Population

The coal-mining industry was chosen as a target industry because of its high rate of workers' compensation claims for cold exposure injuries [Jensen, 1983] and the very detailed MSHA data concerning occupational injuries and working hours in the mines. All mine operators are required by law to report injuries, illnesses, and employee working hours to the MSHA. The requirements to report for MSHA are the same in all states. The definition of occupational classes in MSHA for the mining industry is not the same as the SIC-Manual definition, but analogous to it. Oil and gas extraction is not included in the mining industry as defined by MSHA. Above-ground mining operations are found in both surface mines and underground mines. To permit separate rate calculations for surface compared to underground operations, employee hours and injuries for surface operations were separately obtained from both mine types. Working hours per state were provided for each state by calendar quarter. Estimates for each day in this quarter for the number of working hours were obtained by dividing the quarterly estimate by 91.25. Injury rates were then calculated per 100 person-years by multiplying the rates times 200,000 (this assumes a person works an average of 2,000 hours per year).

Injuries were obtained from the coded injuries reported on the Part 50 mine accident injury and illness report [MSHA, 1996]. This report includes coded items for the nature of injury or illness and source (direct cause) of the injury or illness. Additional uncoded information is supplied by a narrative describing conditions contributing to the occupational injury or illness. The focus of this report is on the coded data fields. Illnesses (such as dust diseases of the lungs, skin diseases, poisoning, etc.) were excluded from the analysis with the exception of the category of illnesses that included those due to environmental heat and cold. For the period 1985–1990, 84% of the total coal mining injuries were reported in the seven states (Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Virginia, West-Virginia) having the most working hours in the mining industry. For these seven states a total of 72,716 injuries were reported from the mines, of which 52,455 (72%) occurred in underground operations and 20,261 (28%) occurred in surface operations. These states were used in the detailed analyses of this study.

Weather Data

The National Climatic Data Center in Asheville, NC provided temperature and wind data that allowed the calculation of the relationship between daily temperature and injury. The data we used were the weather variables which are reported daily by the major metropolitan weather stations in each of the seven states. Each state provided four to seven major metropolitan weather stations, and these data were averaged across the state, giving a state average for each day from January 1, 1985, to the December 31, 1990 (2191 days). The temperatures are the average of the high and low temperature over a 24-hour period, thus the highest average daily temperature did not exceed 89°F and the coldest average daily temperature was not below 3°F. Wind speed was used as wind-indicator instead of wind chill index [Holmer, 1993], since the wind chill index is highly related to chilling of exposed bare skin, whereas we were more concerned to assess the overall effects of wind, separately and combined with temperature.

Statistical Analyses

Linear regression was used to model the effect of daily temperature on injury rate versus integer degrees. For these models, rates were calculated as the number of injuries summed for every integer average temperature divided by the total number of days at that temperature, separately for each state. These regressions were then weighted by the sum of working hours during days of that average temperature. For cold exposure injuries ($n = 49$) and slip and fall injuries ($n = 10{,}933$), Poisson regression was used to model grouped injury rates by grouped temperature classes. Nine discrete temperature subgroups were used. For these analyses, the total number of injuries in each temperature class was modeled. Weights for these models were the natural logarithm of the total number of hours worked in the corresponding temperature class. This model allows relative injury risks for each temperature class compared to a reference temperature class to be estimated. To illustrate the combined effects of wind and temperature on cold exposure injuries, the average daily temperatures were collapsed into four groups, and wind categories collapsed into two groups.

RESULTS

Table I presents the distribution of injuries by source of injury grouped into seven categories. In the MSHA data, the source of injury is the immediate substance, exposure, or bodily motion which produced the injury. This scheme allows for the identification of injuries caused directly by the cold (Ice, Snow, or Cold–atmospheric, environmental Not Elsewhere Classified). As is apparent from Table I, cold exposure injuries only accounted for 49 of 72,716 injuries, the overwhelming majority being incidents related to sources such as metal and mineral items, underground work environment, machinery, tools, and vehicles. For the 49 cold exposure injuries in the mining industry, ice was the most common cold source (74.7%). Atmospheric cold accounted for 16.9% and snow, 8.4% of the cold exposure injuries.

Table II shows the nature of injury distribution for cold exposure injuries and for all injuries. Two 'nature of injury' categories, freezing, and strains and sprains, are significantly over-represented in the 49 cold exposure injuries. Strains and sprains are the most common nature class of all

TABLE I. Distribution of Injuries Grouped by Source of Injury

Source	Frequency	Percent
Metal and mineral items	27863	38.3
Underground work environment or area	7009	9.6
Machines (shop)	6087	8.4
Hand tools	5049	6.9
Electric apparatus	4598	6.3
Vehicles	4617	6.4
Structures, surfaces, and buildings (inside and outside)	4233	5.8
Cold	49	0.1
Heat	10	0.01
Other	13201	18.2
Total	72716	100

TABLE II. Distribution of Cold Injuries in Relation to All Injuries Grouped by the Nature of the Injury

Nature of injury	All injuries	Percent	Cold exposure injuries	Percent
Freezing	12	0.01	11	22.5
Strain/sprain	28,444	39.1	24	48.9
Cuts/lacerations/wounds	11,068	15.2	6	12.2
Rupture/fracture	7,772	10.7	3	6.1
All other	25,420	34.9	5	10.2
Total	72,716	100	49	100.0

TABLE III. Distribution of Circumstances that Contributed to the Injury Producing Incident

Accident category	All injuries	% Frequency	Cold exposure injuries	% Frequency
Handling material	25,138	34.6	5	10.2
Slips and Falls	10,933	15	29	59.2
Machinery	10,462	14.4	2	4.1
Hand Tools	7,585	10.4	0	0.0
Powered Haulage	8,388	11.5	1	2.0
Others	10,210	14	12	24.5
Total	72,716	100.0	49	100.0

injuries (36.6%) and for cold exposure injuries (48.9%). The nature of cold exposure injuries was more often other than freezing injuries (Table II, Fig. 1).

Table III shows the distribution of circumstances that contributed to the injury-producing incident, grouped by categories of the accident, injury and illness (accident) scheme. The percent distribution of slips and falls was 15% for all injuries compared to 59% for the cold exposure injuries. The accident scheme is analogous to the external cause codes of the International Classification of Diseases, although these categories for accidents are uniquely specialized to the mining industry.

Table IV presents the weighted linear regression analysis of average daily temperature vs. injury rates for accident subgroups, adjusted for differences in state injury rates, and assuming a linear relationship between temperature and injury rate. For each of the regressions for categories of "Handling Materials," "Machinery," "Powered Haulage," and "Hand Tools," the linear coefficient for temperature was significant and in the positive direction. For these five external cause categories, as the average daily temperature increased, the average injury rate for that day also tended to increase. The "Other" category showed a negative linear association between temperature and injury; however, this was not statistically significant. The last row in Table IV shows that slips and fall rates were negatively associated, that is, rates tended to increase with decreasing average daily temperatures. A quadratic model fit for slips and falls indicated significant evidence that the trend between injury rate and temperature was not linear ($P = 0.003$); the interaction term between temperature and state from this model was not significant ($P = 0.097$), indicating that association of temperature with slips and fall injury rates was similar across all seven states.

TABLE IV. Weighted Linear Regression of Average Daily Temperature in Degrees F vs. Injury Rates by Different Accident Categories

Accident category	F- value	*P*-value	Direction of temperature main effect
Handling materials	19.61	< 0.001	Positive
Machinery	13.58	< 0.001	Positive
Powered haulage	4.5	0.034	Positive
Hand Tools	9.68	0.002	Positive
Other	0.28	0.595	Negative
Slips and Falls	5.46	0.02	Negative

Figure 2 shows a plot of grouped temperatures vs. slip and fall injury rates for the 10,933 slip and fall injuries. It is apparent that the association is not linear, appearing to be linked to quite low temperatures, rather than a continuous linear association across all temperature categories. Table V gives the rate ratios for each temperature class vs. 70–79°F, calculated from the same data as in Figure 2.

Injuries which required days away from work accounted for 83% (9,073/10,933) of the slip and fall

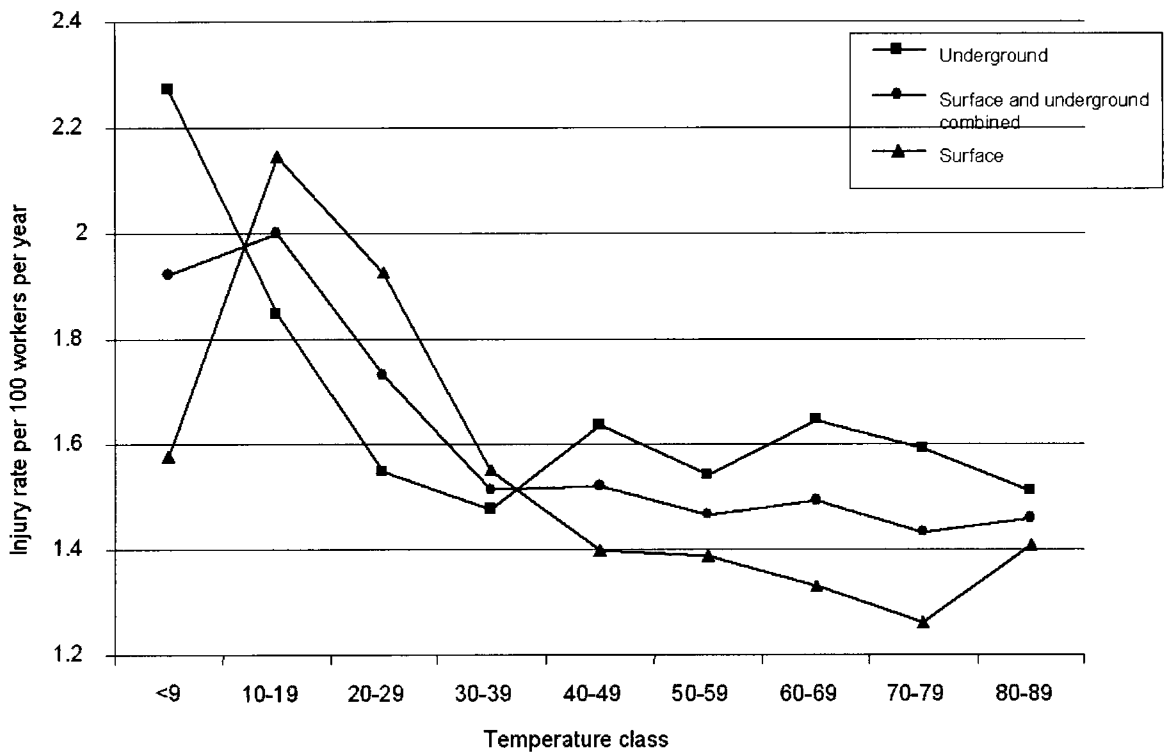

FIGURE 2. Rates of slip/fall injuries per 100 workers per year in surface- and underground-level mine operations in each temperature class.

TABLE V. Poisson Regression of Average Daily Temperature Category vs. Injury Rate for Slip and Fall Injuries

Parameter	Rate ratio	*P*-value
0–9°F*	1.34	0.0475
10–19°F*	1.39	0.0001
20–29°F*	1.21	0.0001
30–39°F*	1.06	0.0966
40–49°F*	1.06	0.0557
50–59°F*	1.03	0.4440
60–69°F*	1.04	0.1666
80–89°F*	1.02	0.7294

*vs. 70–79°F.

injuries. When comparing results of temperature class vs. slip and fall injury rates between surface and underground operations (Fig. 3), for injuries requiring days away from work, the relationship to cold (except for the lowest temperature category) is stronger in surface operations. For the injuries that do not result in death nor days away from work activity, the relation to cold is not as strong as for injuries requiring days away from work. Slip and fall injuries which led to death, permanent disability, or days of restricted work activity only represented very few cases (320/10,033).

Table VI shows the frequency counts and percentage distributions for discrete temperature ranges by state and an average over all seven states during the 6-year period. This table indicates about 11% of the days, or about 152 days, averaged 29°F or less during 1985–1990. The states with the most days below 30°F were Illinois and Ohio. The state with the fewest cold days was Virginia.

Table VII is the weighted linear regression analysis of temperature on the rate of cold exposure injuries. The negative linear coefficient for temperature indicated that as temperature decreased, cold exposure injuries increased. The interaction term between temperature and state was significant ($P = 0.03$), indicating that the association of temperature with cold exposure injury was not the same across all seven states.

Figure 4 shows a plot of grouped temperatures vs. cold exposure injury rates for the 49 cold injuries from the Poisson regression. These data show a strong negative relationship between cold exposure injuries and temperature. A slightly higher direct cold-exposure injury rate was apparent in surface operations compared to underground, but the same relationship held across temperature classes.

Table VIII gives incidence rate ratios for two Poisson models. Model 1 gives rate ratios for the incidence rates of cold exposure injuries in Figure 4, before controlling for the effect of wind. Model 2 gives analogous rate ratios for the incidence rates of the combined effects of wind and temperature. The results from model 2 show that adding wind data contributed little. Goodness of fit tests with a χ^2 statistic of 0.4186 and 3 df were not significant at

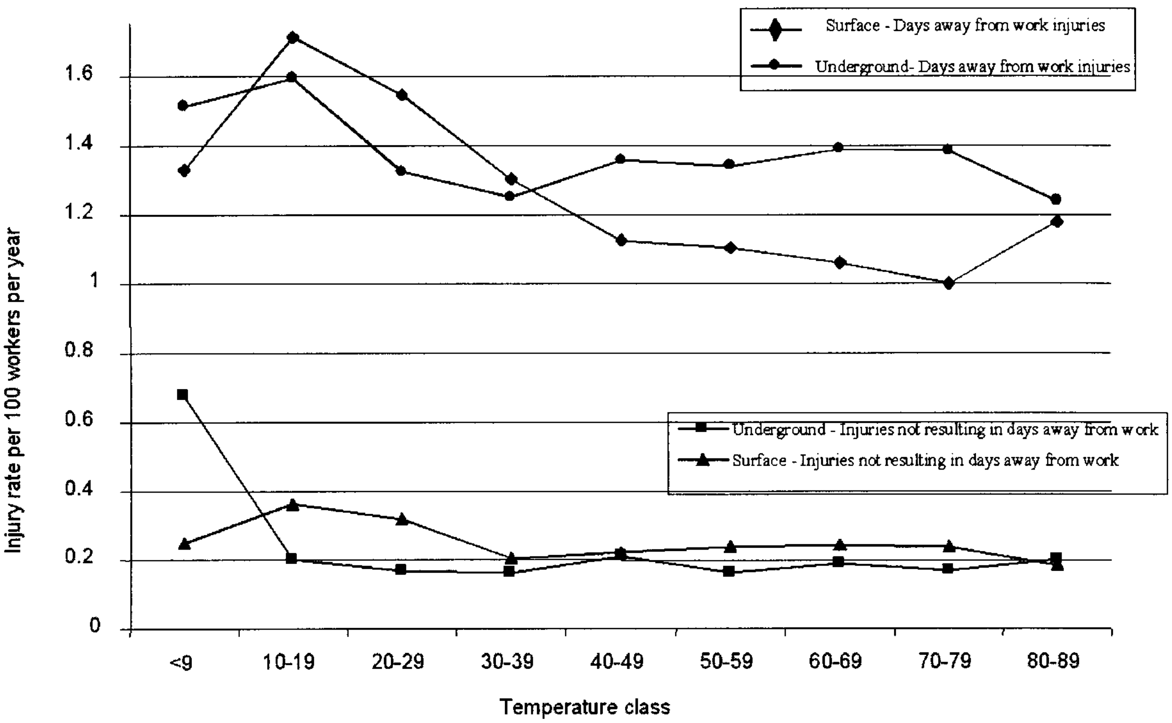

FIGURE 3. Rates of slip/fall injuries per 100 workers per year in different severity and temperature classes in surface-level and undergound mines.

TABLE VI. Discrete Average Daily Temperature Category Frequency Counts and Percentage Distributions in the Seven States During 1985–1990

Temperature category*	IL	WV	PA	VA	IN	OH	KY	Total days	Ave. %	Ave. day
< 9°F	32	3	3	0	13	11	4	66	0.4	9.4
10–19°F	120	51	71	13	88	98	49	490	3.2	70.0
20–29°F	196	146	187	83	159	195	101	1067	7.0	152.1
> 29°F	1,843	1,991	1,930	2,095	1,931	1,887	2,037	13,714	89.4	1959.6
Total	2,191	2,191	2,191	2,191	2,191	2,191	2,191	15,337	100.0	2191.10

*Mean daily temperature in degrees Fahrenheit.

TABLE VII. Weighted Linear Regression of Average Daily Temperature vs. Injury Rates for Cold Exposure Injuries

Cold exposure injuries	F-value	*P*-value	Direction of temperature main effect
Ice, snow, atmospheric and environmental cold	52.80	< 0.0001	Negative

$P = 0.9363$, implying that there is no interaction between the temperature and wind classes.

DISCUSSION

The daily ambient temperature of a state as calculated here is a rough estimate of the ambient temperature of the location where the injury actually happened. How much the estimate differs from the true temperature at the mine locations is unknown. Furthermore, the air temperature in underground mines does differ from the ambient environmental air temperature. The air temperature in underground mines remains relatively constant, and is approximately equal to the mean of the annual range of temperatures (Lynn Rethi, personal communication). Despite the relative constancy of temperatures in underground mines, cold air

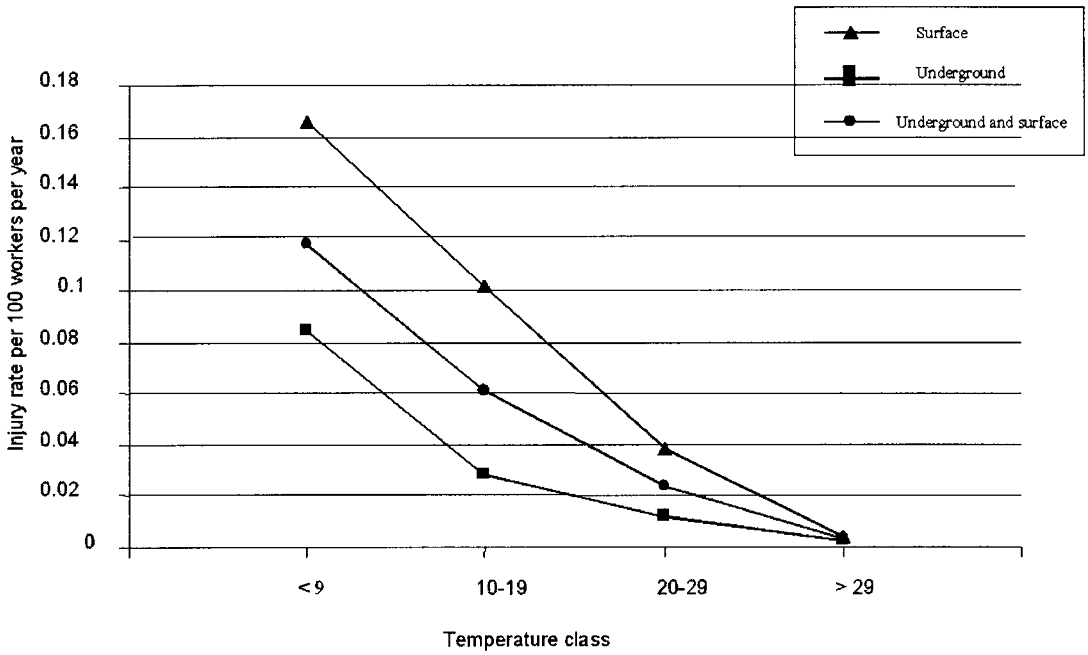

FIGURE 4. Rates of cold exposure injuries per 100 workers per year in surface- and undergound-level mine operations in each temperature class.

TABLE VIII. Poisson Regression of the Combined Effects of Wind and Temperature vs. Injury Rates for Cold Exposure Injuries

Parameter	Rate ratio	*P*-value
Model 1 Temperature only		
Temperature		
> 29°F	Referent	
20–29°F	8.03	< 0.0001
10–19°F	21.23	< 0.0001
0–9°F	40.74	< 0.0001
Model 2 Temperature and Wind		
Temperature		
> 29°F	Referent	
20–29°F	7.45	< 0.0001
10–19°F	19.75	< 0.0001
0–9°F	36.8	< 0.0001
Wind speed		
≤ 9 miles per hour	Referent	
> 9 miles per hour	1.4	0.2485

from the surface can be felt underground near the entrance of mine shafts and slopes. Supplies and equipment brought down from the surface also can introduce snow, ice, frost, or water to the underground mine environment (Thomas Bobick, personal communication).

A distinction needs to be made between cold exposure injuries and cold-associated injuries. Direct cold exposure injuries have a direct physiological basis due to tissue cooling and are manifested mainly as frostbite or hypothermia (right side of Fig. 1). Cold-associated injuries occur through a variety of causal pathways, including body cooling, environmental sources such as increased slipperiness, or combinations of body and environmental causes Fig. 1).

A number of publications, mainly from emergency rooms and hospital registries, have documented the risk of fractures following ice or freezing rain storms [Levy et al., 1987; Bjornstig et al., 1997; Smith and Nelson, 1998; Jacobsen et al., 1995; Lewis and Lasater, 1994; Parker and Martin, 1994; Ralis, 1981, 1986]. There is little dispute that ice and freezing rain lead to increased fracture rates in the general population. Our concern was with cold, not exclusively precipitation, though precipitation during cold weather poses special risks of slips and falls.

There are several reasons why the data presented here should be considered an undercount for cold exposure injuries associated with mining. One reason is that the MSHA reporting system is a passive surveillance system which relies on the injured worker to bring the injury to the attention of the mine operator or contractor. Many hypothermia and frostbite injuries are unlikely to be brought to the attention of the management. Another reason is that injuries with a gradual as opposed to instantaneous onset may go unrecorded, because of the emphasis on reporting instantaneous trauma from accidents. This bias toward instantaneous trauma may be present even in mines where the operator has been an active participant in surveillance for injuries. MSHA reporting is also oriented toward machinery related, powered vehicle related, and other sources of traumatic injury unique to mining operations. The cold exposure injuries may be not reported or recorded as effectively as other more familiar sources of injuries. In addition to under reporting, one must consider whether workers are exposed to risk at the lowest temperatures. Active surveillance data which record tasks occurring at the worksite, in addition to total worker hours, and with trained reporting would help to sort out whether the work done at warmer temperatures is the same as that done during the coldest weather.

Association Between Traumatic Injuries and Ambient Temperature

There was a greater rate of slip and fall injuries as ambient temperatures decreased. This association for slips and falls has not been reported earlier in the occupational literature. Earlier reports of a close correlation between injuries and cold temperatures have concerned the correlation between freezing and frostbite injuries and cold weather [Sinks, 1986; Brahdy, 1935]. The association we observed between cold exposure injuries in workers and temperature is expected, but the association between slip and fall injuries and temperature is less obvious, and the causal connections less well understood. The direct causes of accidents involving slip and fall injuries at a freezing temperature may be cold associated changes in the working environment like increased slipperiness, uneven frozen roads or there may be changes in the body such as clumsiness caused by reduced body temperature (Fig. 1). Workers compensation data from the Liberty Mutual Insurance Company showed a higher rate (per working days of each month) of slip and fall injuries during the months of December, January, February, and March [Leamon and Murphy, 1995]. Because 85% of the Liberty Mutual slip and fall injuries occurred indoors, the authors proposed that outdoor weather conditions may affect the rate of indoor slips and falls through changed footwear, contaminants, or walked-in water. The slipperiness of snow and ice are mentioned as an important reason for losing one's balance during the cold season [Gronqvist, 1984; Honkanen, 1982; Manning et al., 1988]. The remaining other accident categories (Handling materials, Machinery, Tools, Powered Haulage) did not show a similar negative association. Because of ice and snow on ladders, stairways and steps, safer working practices with respect to slips and falls on cold working days may not be as easy to adopt as safer practices relating to the other accident categories.

Cold Exposure Injuries

Freezing was reported as a nature of the injury in cold exposure injuries for only 22.5%. The R^2 results for cold exposure showed that temperature explains only 10% of the cold exposure injuries in this study group. There was a negative association between temperature and the rate of cold exposure injuries seen even at temperatures over 30°F. 65.3% of the cold exposure injuries occurred at temperatures of 20–40°F. The starting point of a statistically significant increased risk of injury in the present study (20–29°F) was similar to the 20°F temperature level reported by Sinks et al. [1987].

Cold as an Occupational Hazard

When the ambient temperature is low, decreased skin temperatures are commonly observed, even with the use of recommended cold weather clothing [Hassi, 1989; Anttonen and Virokannas, 1994]. Decreases in skin temperature are associated with loss of flexibility and neuromotoric disturbances [Enander, 1987]. Cold causes frozen ground, a colder working environment and a variety of physiological disturbances. The present study showed a negative association between environmental temperature and slip and fall injuries.

The public health impact of cold environmental temperatures on injuries to mine workers is considerable, when the percentage of days below 29°F is considered. While the negative slope between environmental temperature and slip and fall injuries is not large in the U.S. mining data, the public health impact is more closely related to the percentage of days below 29°F, than to the slope across the entire range of temperatures. In these seven states about 11% of the days had environmental temperatures between 0 and 29°F. In colder climates with a higher percentage of days between 0 and 29, the public health impact would be greater, assuming the same correlation holds.

Caution and Limitations of the Data

The statistical results of this study should be interpreted with caution. A major concern is that environmental cold does not necessitate exposure to risk; activities causing exposure to cold may be reduced on the days of the coldest temperatures, effectively attenuating the correlation between environmental temperature and injury risk. Only more demanding research designs which document actual exposure to risk on the coldest days can address this problem. The limitation of MSHA injury data for identifying cold exposure injuries has already been mentioned. Another issue to consider is whether the use of statewide average temperatures faithfully captures local weather conditions. Statewide averages cause some dampening of the association at the extreme ends of temperature. The northern parts of the Midwestern states included in the survey (Ohio, Illinois, Indiana) have winter temperatures several degrees colder each day than the southern portions, and by averaging across the state some of that association will be lost. Similar attenuation also applies to wind speeds. We would consider the strength of the association we observed for slip and fall injuries with temperature as conservative. The contribution of ice, freezing rain or snow separately from that of ambient cold could not be addressed in this report. It is reasonable to assume that precipitation contributed to the association we observed between weather and slip and fall injuries. This can be inferred from the more consistent association of temperature with slips and falls observed for surface mining than for underground mining (Figs. 2 and 3). Data on precipitation, particularly precipitation at the worksite, would be a valuable addition to future studies, and would help sort out the direct effects of ambient air temperature from the effects of ice and snow on environmental surfaces.

The physiological changes reported in cold working environments [Enander et al., 1987; Anttonen and Virokannas, 1994] support the possibility of the effects of cold in all accident classes, including slip and fall. Cooling of tissues diminishes the sense of feeling of the skin and the dexterity of the fingers. Hands lose their physical performance, become weak, senseless and clumsy in the cold environment, which may contribute to injuries. Thick clothing impedes movement which decreases function and reaction speeds. In addition, the discomfort caused by low temperature may diminish the mental motivation, so that attentiveness and ability to concentrate may decrease [Kappes and Mills, 1988]. Whether falls are the only injury class which shows this kind of association should be studied in other industries.

Work in cold environments must be so conducted that worker health and safety are preserved. The present study identifies slips and falls as a clear objective for preventive activities in occupational safety and health. With respect to prevention, direct cold exposure injuries have been successfully prevented by using protective clothing and technical solutions that warm workers [Anttonen et al., 1993; Anttonen and Niskanen, 1995; Niskanen et al., 1994; Pekkarinen et al., 1994]. These advances have been adopted in Finland where the frequency of cold stress exceeding the recommended limits is widely recognized [Anttonen et al., 1993]; Finland is comparable to the northern states of the USA. Categories of injury other than direct cold exposure, such as slips and falls, may have a substantial relationship to cold environments, and although the data presented here suggest that the relationship exists, research that can precisely quantify climate-related traumatic injury risks in individual industries is lacking. An improved illness and injury risk identification from more detailed active surveillance would have great value as a basis for proper prevention.

ACKNOWLEDGMENTS

The authors thank Barry Ryan, Supervisory Coal Mine Inspector from the MSHA Oakland Field Office in Oakland, Maryland, for his valuable help in answering our many questions about mining operations.

REFERENCES

Anttonen H, Niskanen J, Rautiainen A, Rintamäki H. 1993. Prevention of adverse effects of cold on food processing workers by infrared heaters. In: Nielsen R and Jorgensen K, editors. Advances in Industrial Ergonomics and Safety V. London: Taylor and Francis, p. 369–375.

Anttonen H, Virokannas H. 1994. Assessment of cold stress in outdoor work. Arct Med Res 53:40–48.

Anttonen H, Niskanen J. 1995. Prevention of the adverse health effects of cold using infrared heaters. Arct. Med. Res. 54 (Suppl. 2.):55–59.

Bjornstig U, Bjornstig J, Dahlgren A. 1997. Slipping on ice and snow—elderly women and young men are typical victims. Accid Anal Prev 29:211–215.

Brahdy, L. 1935. Frostbite among employees of the city of New York, during the winter of 1933–1934. JAMA 104:529–532.

Enander A. 1987. Effects of moderate cold on performance of psychomotor and cognitive tasks. Ergonomics 30(10):1431–1445.

Grönkvist R. 1984. Long-shoremen's occupational accidents due to loss of balance. (English abstract), Työterveylaitoksen tutkimuksia 2(3):196–205.

Hassi J. 1989. Distinctive health features in arctic settlements. Habitat Intl 13(2):111–113.

Hassi J, Ervasti O, Juopperi K, Rintamäki H, Pihlajaniemi R, Linna T. 1997. Lifetime incidence of frostbite, its association with cold induced white fingers, vibration exposure and outdoor activity in young Finnish men. Book of Abstracts, Scientific Program, International Symposium on Problems with Cold Work, November 16–20, 1997, Stockholm, Sweden.

Holmer I. 1993. Work in the cold. Review of methods for assessment of cold exposure. Int Arch Occup Environ Health 65(3):147–155.

Honkanen R. 1982. The role of slippery weather in accidental falls. J Occup Accid 4:257–262.

Jacobsen SJ, Sargent DJ, Atkinson EJ, O'Fallon WM, Melton LJ. 1995. Population-based study of the contribution of weather to hip fracture seasonality. Am J Epidemiol 141:79–83.

Jensen R. 1983. Workers' compensation claims relating to heat and cold exposure. Professional Safety (September 1983):19–24.

Kappes B, Mills W. 1988. A sample of personality profiles of frostbite patients in Alaska 1980–86. Arct Med Res 47 (suppl. 1):243–245.

Leamon TB, Murphy PL 1995. Occupational slips and falls: more than a trivial problem. Ergonomics 38:487–498.

Lewis LM, Lasater LC. 1994. Frequency, distribution and management of injuries due to an ice storm in a large metropolitan area. Southern Med J 87:174–178.

Levy AR, Bensimon DR, Mayo NE, Leighton HG. 1998. Inclement weather and the risk of hip fracture. Epidemiology 9:172–177.

Manning, DP, Ayer I, Jones CB, Mcohen K. 1982. The incidence of underfoot accidents during 1985 in a working population of 10,000 Merseyside people. J Occup Accid 4:257–262.

Mine, Safety and Health Administration 1996. U.S. Dept. of Labor, Part 50 Accident, Injury and Illness Reports (MSHA, Denver, CO).

Niskanen J, Anttonen H, Pekkarinen A. 1994. Service of snowmobiles in the wilderness and villages. Arct Med Res 53 (suppl. 3):55–60.

Osborne E, Vernon H. 1922. The influence of temperature and other conditions on the frequency of industrial accidents. London: Her Majesty's Stationery Office.

Parker MJ, Martin S. 1994. Falls, hip fractures and the weather. Eur J Epidemiol 10:441–442.

Pekkarinen A. 1994. Occupational accidents occurring in different physical environments with particular reference to indoor and outdoor work. Doctoral dissertation. Oulu, Finland. pp. 148.

Pekkarinen A, Anttonen H, Pramila S 1994. Accident prevention in reindeer herding work. Arctic 47(2):124–127.

Ralis ZA. 1981. Epidemic of fractures during periods of snow and ice. Br Med J 282:603–605.

Ralis ZA. 1986. Epidemics of fractures during periods of snow and ice. Br Med J 293:484.

Ramsey JG, Burford CL, Beshir MY, Jensen RC. 1983. Effects of workplace thermal conditions on safe work behavior. J Safety Res 14:105–114.

Smith RW, Nelson DR. 1998. Fractures and other injuries from falls after an ice storm. Am J Emerg Med 16:52–55.

Sinks T, Mathias C, Halperin W, Timbrook C, Newman S. 1986. Surveillance of work related cold injuries using Workers' Compensation Claims. J Occup Med 29:504–509.

Türk HC, Klinker L. 1986. Zum Einflu\beta der meteorologischen Umweltfaktoren auf die Unfallhäufigkeit. The influence of meteorological environmental factors on accident frequency. Zeitschrift fur die Gesamte Hygiene 12:704–707.

Vernon HM. 1936. Accidents and their prevention. Cambridge, The Cambridge University Press.