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Risks of Hand Tool Injury in U.S. Underground Mining From 1978 Through 1983 Part II: Metal-Nonmetal Mining

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The underground metal-nonmetal (MNM) mining industry represents an environment that is significantly different from other underground mining environments. This paper reports the findings of an investigation of hand tool-related accidents in the underground MNM mining industry over a 6-year period (1978–1983). The sequence of injury components associated with the various hand tools are described. The study revealed that about 85% of all lost work days due to hand tool-related injuries are the result of accidents involving the jackleg drill or scaling bar. The sequences of injury components for these tools and the ergonomic implications associated with these sequences are discussed. Suggestions are given for further research to correct the problems described.

The underground metal-nonmetal (MNM) mining industry represents an environment in which there is a significant risk of hand tool-related injury. This environment is substantially different from that of the underground coal mining industry. In Part I of this study published in the Summer 1988 issue of the *Journal of Safety Research* (Marras, Bobick, Lavender, Rockwell, & Lundquist, 1988), the hand tool risks associated with underground coal mining were described. This paper will focus on the risks of hand tool-related injury (in terms of frequency and severity) in the MNM underground mining industry.

The results presented here represent the findings of an investigation of hand tool accidents in the underground MNM mining industry over a 6-year period (1978–1983). During this period, over 4,000 such accidents, resulting in over 40,000 lost work-

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days, were reported. These figures are a little more than half of those reported for coal mining over the same period. Exposure metric data relating the hours worked in each industry were not available; therefore, the data could not be normalized. However, data from the Mine Safety and Health Administration (MSHA) show that MNM mining had only 22% of the exposure hours of coal mining. Yet MNM mining statistics indicated that MNM mining had 76% as many accidents and 46% as many days lost as coal mining. Therefore, there is reason to believe that hand tool use in underground MNM mining represents a substantial risk to workers.

METAL-NONMETAL MINING

The MNM mining industry is different from the coal mining industry in two primary ways: (a) environment and (b) tools.

Environment

First, the environment is different. Coal mining often requires workers to assume constrained work positions due to low seam height (less than 60 in. [152.4 cm]). In MNM mining, this seldom occurs. In fact, some MNM environments may have seam heights that are well over 12 ft (3.65 m) high. Instead of the workers being confined in their posture, they must reach with long bars to perform tasks such as scaling (removal of loose rock from the roof).

Other environmental factors also affect workers' ability to safely use hand tools. The floors of MNM mines generally consist of irregular broken rock that affects workers' postural stability during tool use. The temperature and humidity also vary much more than in coal mining. Finally, the MNM mining environment may impose more sudden loading upon the body. This is because the visual perception of falling rock may be hindered in extremely high seam mining. Rocks falling from high roof conditions would have greater velocity, giving miners reduced time to detect the falling debris and respond. Therefore, we would expect an increased probability of struck-by and exertion injuries as sudden movements are made in response to rocks falling during the scaling task.

Tools

Second, the tools used in MNM mining are considerably different from the corresponding ones used in coal mining. As in coal mining, the tools used are large and awkward and often impose large moments upon the body. An important tool that is unique to MNM mining is the jackleg drill. This device is large (over 5 ft [1.5 m] long), heavy (over 100 lbs [45.3 kg]), and difficult to control. A pneumatically powered extension leg helps push the drill steel and bit into the rock being drilled. Inexperienced drillers often fight against the drill during its operation and thus impose large forces on their backs and arms.

The other tool that is unique to MNM mining is the scaling bar. This tool is usually longer (6 to 12 ft [1.2 to 3.6 m]) and heavier than the ones used in coal mining. The use of this tool may also impose large moments on the trunk of the worker.

These two tools represent the essence of MNM mining activity and are used more frequently than the other tools. Most other tools used in MNM mining are similar to those used in coal mining.

Objectives of the Injury Data Analysis

The objectives in analyzing hand tool injury data were three-fold: (a) to define the circumstances (accident type, part of body injured, activity at the time of injury, etc.) of the lost-time hand tool injuries; (b) to define the probability of occurrence for each circumstance; and (c) to define the sequence of injury-component and identify the most probable and most severe component links.

METHOD

As in the coal mining study, injury reports contained in the MSHA database were used to evaluate the risk of hand tool injuries in the MNM underground mining industry. This database had been found to be the best source available for a quantitative evaluation of hand tool injuries in underground mining.

The injury components analyzed were identical to those used in the analysis of hand tool-related injuries in the underground coal mining industry (Marras et al., 1988). These components were: (a) the type of tool used during the accident, (b) the type of accident, (c) the part of the body injured, and (d) the nature of the injury.

As in the coal mining analysis, the initial analysis described the sequence of injury-component events for individual years and then for the combined total (1978–1983), using frequency of occurrence and lost days as dependent measures. For the combined years of data, the conditional relationships among the injury components were established and were represented by probabilistic tree diagrams. The injury-component sequences were also ranked in terms of days lost, making it possible to identify the sequences that represented the greatest risk in terms of frequency and severity.

Finally, several in-depth analysis techniques were used, including task analyses, worker interviews, narrative reports of accidents, and ergonomic assessments of tool use. (For a complete description of the data collection and analysis techniques, see Marras et al., 1988.)

RESULTS

The severity of injuries (measured in lost days) associated with hand tool use in the MNM mining industry is shown in Table 1 for the seven hand tools identified in this study. This table indicates that the majority of lost time is associated with the use of two tools. In fact, the jackleg drill and the scaling bar account for nearly 85% of the lost days due to hand tool accidents. Moreover, the average lost days per accident are substantially greater for the scaling bar than for any other tool. Because the jackleg drill and the scaling bar basically characterize the hand tool risk in underground MNM mining, only these tools will be discussed in this investigation.

Jackleg Drill

Figure 1 summarizes the injury components associated with jackleg drill injuries for the 6 years of interest. Of the hand tools used in underground MNM mining, the

TABLE 1
LOST DAYS ASSOCIATED WITH VARIOUS TOOLS
USED IN METAL-NONMETAL MINING, 1978–1983

Tool	Number of Accidents	Total Days Lost	Average Days Lost Per Accident	% of Total Days Lost, All Hand Tool Accidents
Jackleg drill	1,913	18,049	9.43	44.11
Scaling bar	1,033	16,546	16.02	40.44
Pry bar	397	2,663	6.69	6.51
Hammer and axe	405	1,902	4.69	4.65
Wrench	189	1,170	6.16	2.86
Knife	162	304	1.87	0.74
Jack	61	283	4.64	0.69

jackleg drill accounted for the greatest frequency of injuries and for the second largest average lost days per accident. Figure 1 indicates that over 62% of the injuries are due to struck-by accidents. The parts of the body most often struck in these accidents are arms, heads, and legs. Cuts are usually sustained by these body parts and usually result in few lost days. Fracture injuries occur most frequently to the leg and arm. These injuries usually result in a large number of lost days. This is particularly true if the leg is involved.

Caught injuries are the next most likely injuries to occur during jackleg drill use. Over 90% of the time, a caught injury will involve the arm. These injuries typically result in a break or cut. In both situations, the resulting average lost days is between 5.5 and 7.5. This low number indicates that most of these injuries occur to the hands and fingers.

The next most frequent accident involves exertion injuries. These accidents result in a greater number of average lost days (11.51) than do struck-by (9.50) and caught (6.69) injuries. The vast majority (78%) of the exertion injuries involve the trunk. Of these injuries, 92% involve tears. This sequence of events suggests that musculoskeletal injuries to the back are quite common and severe. In fact, of the frequently occurring injuries, this sequence is associated with the greatest average lost-time risk (9.91 days).

The final major branch of the injury-component sequences in Figure 1 involves fall injuries. These injuries account for about 8% of jackleg drill injuries and result in an average of 12.55 lost days. The arm and trunk are involved most often. Injuries to the arm occur about 31% of the time and result in cuts that have a low lost-time value (0.47 days). The trunk, on the other hand, is involved more frequently (40%) and most often results in muscle tears with a substantial number of lost days (17.87). This sequence involving the trunk also suggests that significant musculoskeletal injuries occur to the back during falls. This finding is consistent with other findings regarding lower back disorders (Manning, Mitchell, & Blanchfield, 1984).

Scaling Bar

Scaling bar use represents the other major hand tool risk in the MNM underground mining industry. Over 40% of all lost days due to hand tool-related injuries are caused by this tool. Figure 2 shows the sequence-of-injury components associated with the scaling bar. Nearly 75% of these injuries involve struck-by accidents, resulting in a mean of 14.64 lost days. The body parts affected most often are legs and arms. Each of these are involved in approximately 30% of the struck-by accidents. In most cases, cuts are the predominant nature of injury from struck-by accidents. These cuts generally result in fewer days lost than do other types of injuries. Fracture injuries also occur frequently to the arm, leg, and trunk and usually result in a large number of average lost days. Finally, multiple injuries due to struck-by accidents occur with moderate frequency and result in a significant number of average lost days.

Injuries due to falls are also involved in a significant number of scaling bar accidents. Over 8% of injuries involve falls, and they result in over 20 average lost days. These injuries involve either the arm, leg, or trunk, and the most common nature of injury is cuts. Unlike cuts with other accident sequences, cuts caused by falls during scaling bar use result in a substantial number of mean lost days (9.72 to 21.67).

One other injury-component sequence is worthy of mention. This involves exertion injuries to the trunk resulting in muscle tears. This sequence represents about 5% of scaling bar injuries. Yet, it results in over 19 average days lost and ranks third in total days lost with better than 1,005 lost days for the 6-year period. As with most similar sequences, this sequence indicates a low back musculoskeletal disorder due to use of this tool.

DISCUSSION

The types of injury components associated with the various tools have been ranked and are shown in Table 2. This table indicates that struck-by, exertion, and fall injuries associated with the jackleg drill and the scaling bar represent nearly 80% of all

FIGURE 1
JACKLEG DRILL USE RISK SEQUENCES

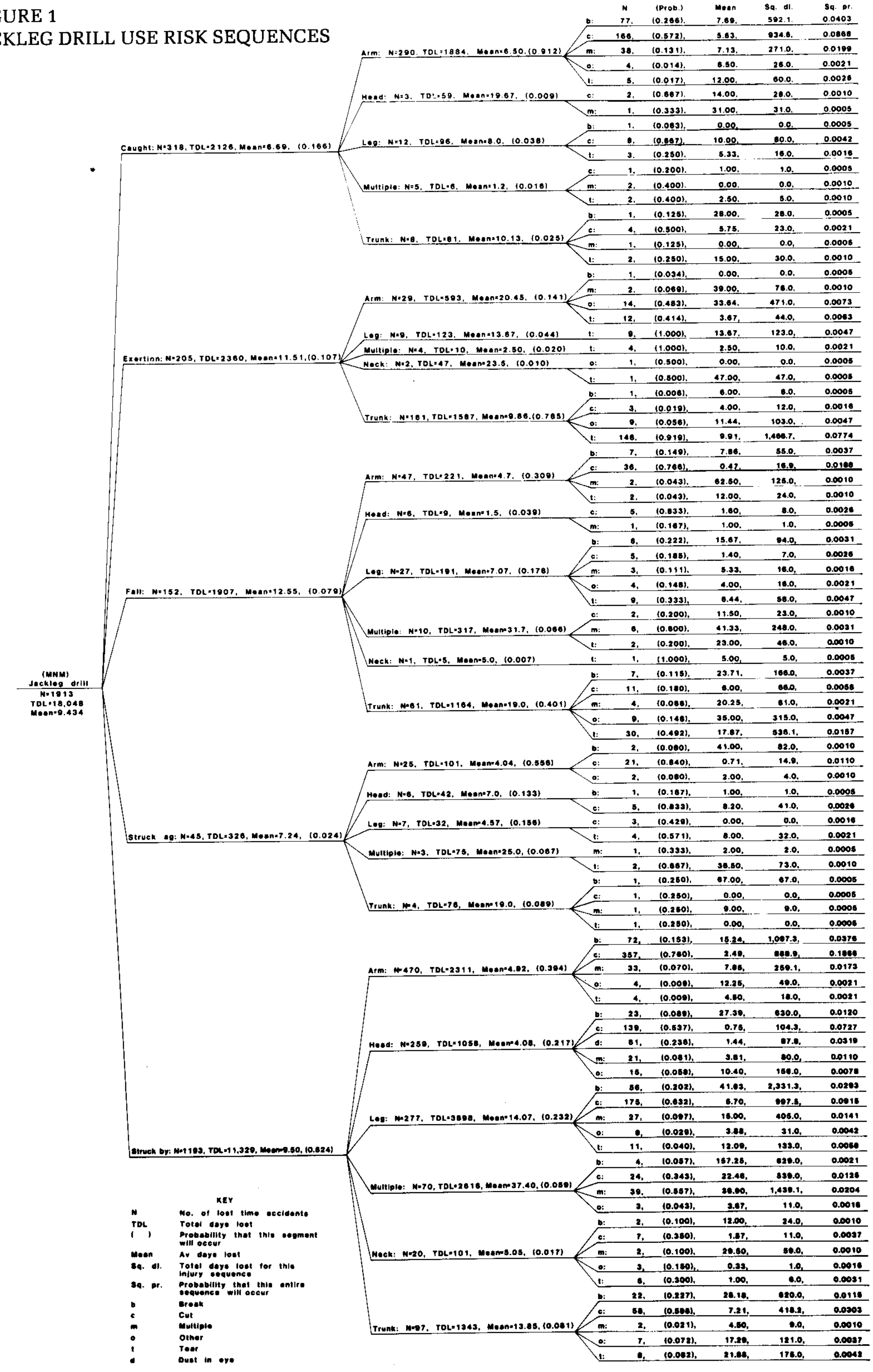


FIGURE 2
SCALING BAR USE RISK SEQUENCES

(MNM) Scaling bar: N=1033, TDL=16,546, Mean=16.017

			N	(Prob.)	Mean	Sq. dl.	Sq. pr.
Caught: N=48, TDL=323, Mean=6 73, (0.046)	Arm: N=44, TDL=278, Mean=6.32, (0.916)	b:	14,	(0.318),	3.71,	51.9,	0.0136
		c:	24,	(0.545),	8.25,	198.0,	0.0232
		m:	6,	(0.136),	4.67,	28.0,	0.0058
	Head: N=2, TDL=0, Mean=0, (0.042)	b:	1,	(0.500),	0.00,	0.0,	0.0010
		c:	1,	(0.500),	0.00,	0.0,	0.0010
	Leg: N=2, TDL=45, Mean=22.50, (0.042)	c:	2,	(1.000),	22.50,	45.0,	0.0019
Exertion: N=67, TDL=1346, Mean=20.09, (0.065)	Arm: N=3, TDL=32, Mean=10.67, (0.045)	c:	1,	(0.333),	0.00,	0.0,	0.0010
		t:	2,	(0.667),	16.00,	32.0,	0.0019
	Leg: N=6, TDL=214, Mean=35.67, (0.090)	t:	6,	(1.000),	35.67,	214.0,	0.0058
	Multiple: N=1, TDL=92, Mean=92.0, (0.015)	o:	1,	(1.000),	92.00,	92.0,	0.0010
	Neck: N=4, TDL=1, Mean=0.25, (0.060)	t:	4,	(1.000),	0.25,	1.0,	0.0039
	Trunk: N=53, TDL=1007, Mean=19.0, (0.791)	o:	1,	(0.019),	2.00,	2.0,	0.0010
		t:	52,	(0.981),	19.33,	1,005.2,	0.0503
Fall: N=89, TDL=2465, Mean=27.7, (0.086)	Arm: N=28, TDL=313, Mean=11.18, (0.315)	b:	1,	(0.036),	61.00,	61.0,	0.0010
		c:	25,	(0.893),	9.72,	243.0,	0.0242
		m:	2,	(0.071),	4.50,	9.0,	0.0019
	Leg: N=21, TDL=1021, Mean=48.62, (0.236)	b:	6,	(0.286),	98.67,	592.0,	0.0058
		c:	3,	(0.143),	21.67,	65.0,	0.0029
		m:	1,	(0.048),	29.00,	29.0,	0.0010
		t:	11,	(0.524),	30.45,	335.0,	0.0106
	Multiple: N=11, TDL=313, Mean=28.45, (0.124)	c:	2,	(0.182),	6.50,	13.0,	0.0019
		m:	5,	(0.455),	38.20,	191.0,	0.0048
		o:	2,	(0.182),	0.00,	0.0,	0.0019
		t:	2,	(0.182),	54.50,	109.0,	0.0019
	Neck: N=1, TDL=23, Mean=23.0, (0.011)	t:	1,	(1.000),	23.00,	23.0,	0.0010
	Trunk: N=28, TDL=795, Mean=28.39, (0.315)	b:	1,	(0.036),	221.00,	221.0,	0.0010
		c:	12,	(0.429),	15.33,	184.0,	0.0116
		m:	1,	(0.036),	56.00,	56.0,	0.0010
		o:	2,	(0.071),	124.50,	249.0,	0.0019
		t:	12,	(0.429),	7.06,	85.0,	0.0116
Struck ag: N=55, TDL=1078, Mean=19.6, (0.053)	Arm: N=31, TDL=74, Mean=2.39, (0.564)	b:	5,	(0.161),	6.80,	34.0,	0.0048
		c:	23,	(0.742),	1.39,	32.0,	0.0223
		m:	1,	(0.032),	0.00,	0.0,	0.0010
		o:	1,	(0.032),	4.00,	4.0,	0.0010
		t:	1,	(0.032),	4.00,	4.0,	0.0010
	Head: N=2, TDL=10, Mean=5.0, (0.036)	c:	1,	(0.500),	4.00,	4.0,	0.0010
		o:	1,	(0.500),	6.00,	6.0,	0.0010
	Leg: N=12, TDL=256, Mean=21.33, (0.218)	b:	2,	(0.167),	122.00,	244.0,	0.0019
		c:	6,	(0.500),	1.67,	10.0,	0.0058
		t:	4,	(0.333),	0.50,	2.0,	0.0039
	Multiple: N=4, TDL=117, Mean=29.25, (0.073)	c:	2,	(0.500),	14.00,	28.0,	0.0019
		m:	1,	(0.250),	83.00,	83.0,	0.0010
		t:	1,	(0.250),	6.00,	6.0,	0.0010
	Neck: N=1, TDL=0, Mean=0, (0.018)	t:	1,	(1.000),	0.00,	0.0,	0.0010
	Trunk: N=5, TDL=621, Mean=124.2, (0.091)	c:	4,	(0.800),	154.25,	617.0,	0.0039
		t:	1,	(0.200),	4.00,	4.0,	0.0010
Struck by: N=774, TDL=11,334, Mean=14.64, (0.749)	Arm: N=236, TDL=1394, Mean=5.91, (0.305)	b:	21,	(0.089),	32.19,	676.0,	0.0203
		c:	190,	(0.805),	3.14,	596.6,	0.1839
		m:	17,	(0.072),	6.41,	109.0,	0.0165
		o:	4,	(0.017),	0.25,	1.0,	0.0039
		t:	4,	(0.017),	2.75,	11.0,	0.0039
	Head: N= 116, TDL=447, Mean=3.85, (0.150)	b:	11,	(0.095),	3.55,	39.0,	0.0106
		c:	74,	(0.638),	0.89,	65.9,	0.0716
		d:	14,	(0.121),	2.21,	31.0,	0.0136
		m:	12,	(0.103),	25.75,	309.0,	0.0116
		o:	5,	(0.043),	0.40,	2.0,	0.0048
	Leg: N=226, TDL=4402, Mean=19.48, (0.292)	b:	61,	(0.271),	47.43,	2,893.2,	0.0591
		c:	129,	(0.571),	5.05,	651.5,	0.1249
		m:	25,	(0.111),	19.36,	484.0,	0.0242
		o:	5,	(0.022),	9.80,	49.0,	0.0048
		t:	6,	(0.027),	54.00,	324.0,	0.0058
	Multiple: N=96, TDL=3207, Mean=33.41, (0.124)	b:	10,	(0.104),	100.30,	1,003.0,	0.0097
		c:	35,	(0.365),	13.60,	476.0,	0.0339
		m:	43,	(0.448),	37.70,	1,621.1,	0.0416
		o:	6,	(0.063),	4.83,	29.0,	0.0058
		t:	2,	(0.021),	39.00,	78.0,	0.0019
	Neck: N=17, TDL=395, Mean=23.24, (0.022)	b:	2,	(0.118),	18.50,	37.0,	0.0019
		c:	4,	(0.235),	0.00,	0.0,	0.0039
		m:	1,	(0.059),	16.00,	16.0,	0.0010
		o:	1,	(0.059),	0.00,	0.0,	0.0010
		t:	9,	(0.529)	38.00,	342.0,	0.0087
	Trunk: N=83, TDL=1489, Mean=17.94, (0.107)	b:	18,	(0.217),	45.44,	817.9,	0.0174
		c:	44,	(0.530),	4.73,	208.1,	0.0426
		m:	10,	(0.120),	26.20,	262.0,	0.0097
		o:	2,	(0.024),	20.50,	41.0,	0.0019
		t:	9,	(0.108),	17.78,	160.0,	0.0087

KEY

N	No. of lost time accidents
TDL	Total days lost
( )	Probability that this segment will occur
Mean	Av days lost
Sq. dl.	Total days lost for this injury sequence
Sq. pr.	Probability that this entire sequence will occur
b	Break
c	Cut
m	Multiple
o	Other
t	Tear
d	Dust in eye

TABLE 2
TOP 10 ACCIDENT TYPES IN METAL-NONMETAL MINING (1978–1983)
AS A FUNCTION OF LOST DAYS

Rank	Tool	Injury Type	Number of Accidents[a]	Days Lost	% of All Days Lost
1	Scaling bar	STBY	774	11,334	27.70
2	Jackleg drill	STBY	1,193	11,329	27.69
3	Scaling bar	Fall	89	2,465	6.02
4	Jackleg drill	Exert	205	2,360	5.77
5	Jackleg drill	Caught	318	2,126	5.20
6	Jackleg drill	Fall	152	1,907	4.66
7	Pry bar	Exert	104	1,432	3.50
8	Scaling bar	Exert	67	1,346	3.29
9	Hammer and axe	STBY	312	1,314	3.21
10	Scaling bar	STAG	55	1,078	2.63
Total				36,691	89.67

Note. STBY = struck by, Exert = exertion, STAG = struck against.
[a]Lost-time accidents for this tool and injury type (see Figure 1).

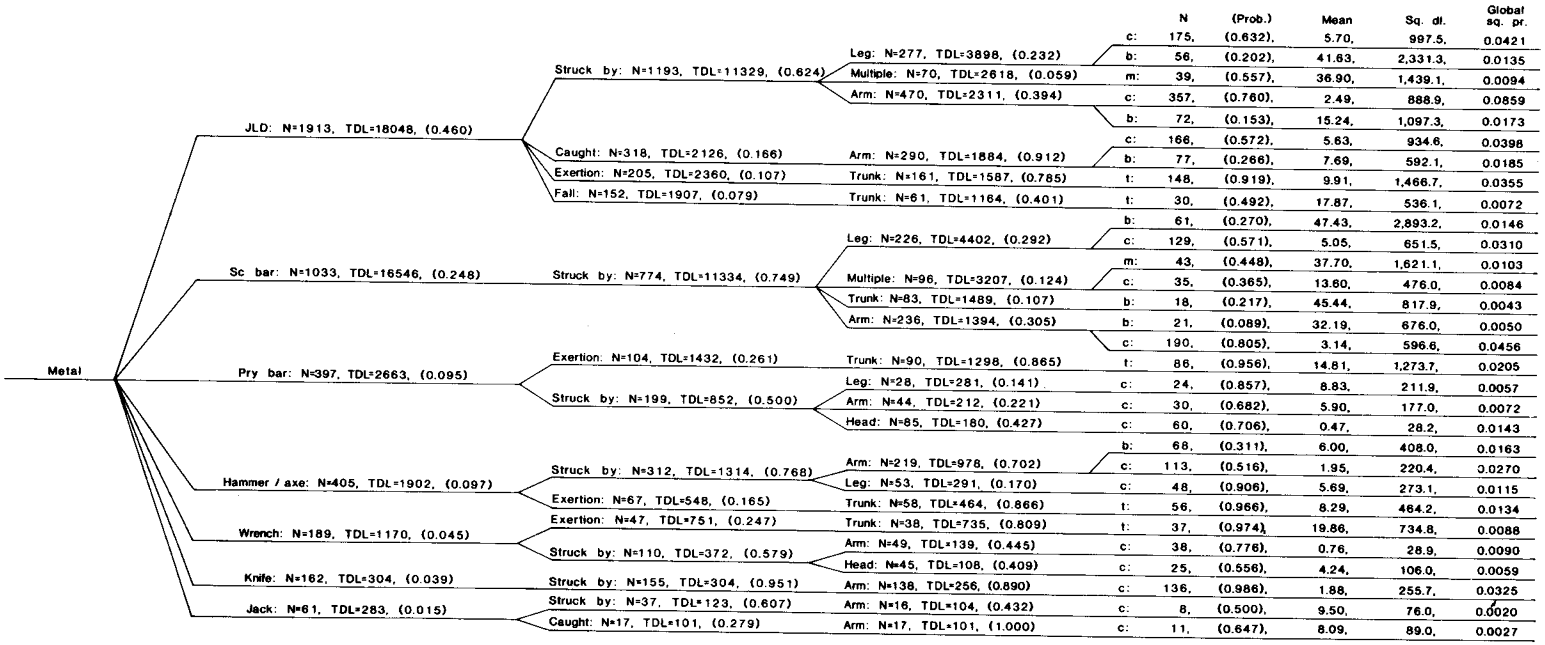
hand tool injuries in underground MNM mining. This table shows that over 55% of the injuries are associated with struck-by injuries due to these two tools.

Figure 3 shows the major injury-component sequences for all tools in underground MNM mining. This figure shows that the predominant injury types associated with most tools involve both struck-by and exertion accidents. Struck-by injuries usually involve the arm or leg, whereas exertion injuries usually are limited to the trunk. As mentioned earlier, trunk exertion injuries typically represent low back, musculoskeletal disorders.

In-depth analyses of the MSHA database suggest possible causes of struck-by accidents during use of the jackleg drill. For example, narrative descriptions of the individual accidents indicate that the leading cause of accidents is rock falls. In fact, tabulation of the narratives has shown that almost 60% of the struck-by accidents can be attributed to rocks falling on miners. Other variations of struck-by accidents involving the jackleg drill include drill falls, in which the miner is struck by the drill during the drilling process, or steel falls in which the drill steel actually strikes the worker. Other less frequent scenarios include instances in which rock slides down the drill steel and hits the worker or the leg of the drill kicks out and hits the miner.

A review of the task analyses involving the jackleg drill has suggested that, due to the awkward working postures often required to operate the drill and the need for constant vigilance on the drill steel and the hole being drilled, workers do not perceive the visual or auditory cues indicating that a rock overhead is about to fall. This suggests that ergonomic changes, such as an improved drill control system, which allows a more suitable work posture and increased visibili-

FIGURE 3
MAJOR RISK SEQUENCES ASSOCIATED WITH HAND TOOL USE IN UNDERGROUND METAL-NONMETAL MINING



KEY

- N — No. of lost time accidents
- TDL — TDL Total days lost
- ( ) — Probability that this segment will occur
- Mean — Av days lost
- Sq. dl. — Total days lost for this injury sequence
- Global sq. pr. — Probability that this sequence occurs relative to all the tools used in underground mnm mining
- b — Break
- c — Cut
- m — Multiple
- t — Tear

ty, would help to minimize the risk of these types of injuries. These same factors would be relevant to incidents that involve rocks sliding down the drill steel or the leg of the drill kicking out.

Struck-by accidents involving the drill or drill steel falling are indicative of the worker's inability to control the drilling process. This is due to a combination of unsatisfactory control mechanisms on the drill, a mismatch between the worker's strength capability and the job requirements, and improper training.

Surprisingly, struck-by accidents involving the scaling bar are due to similar mechanisms. In-depth analyses of the MSHA data indicate that the causal factor in scaling bar accidents is the falling debris from the scaled surface. Narrative descriptions of such accidents suggest that miners tend to scale larger pieces than expected and may not be able to stay clear as the rock falls. Task analyses suggest that the probability of injury due to this mechanism is inversely related to the horizontal distance from the target area. Analyses performed on standing miners engaged in roof scaling indicate that a typical bar angle while thrusting is 65 to 70 degrees. This means that the end of a 6-ft (2 m) bar is 2 ft (.6 m) horizontally from the point of contact with the roof. Because these miners are often standing on broken rock, quick evasive actions are impeded and may account for many of the struck-by leg injuries.

Both the task and data analyses have shown that exertion injuries to the trunk are also responsible for a significant portion of lost time associated with the jackleg drill and the scaling bar. As mentioned previously, most of these injuries are expected to occur in the lower back. The in-depth analyses conducted on the jackleg drill have indicated that back musculoskeletal injuries are possible due to drill lifting and carrying, drill positioning, drill collaring, and drill removal (Marras & Lavender, 1988). Because the jackleg drill weighs in excess of 115 lbs (52 kg), large compression and shear forces are experienced by the back during drill lifting. The drill is often lifted in a cradled position and slung over the shoulder. This requires the miner to assume awkward and often dangerous postures with large asymmetric loads placed on the spine. These postures can be avoided by providing lift points (handles) on the drill that permit the worker to keep the weight of the drill close to the body. This would reduce the moment imposed upon the back, make the load more symmetrically balanced in the sagittal plane, and thus reduce the trunk loading. Other possible means to reduce the risk of injury include the addition of a carrying strap for the drill and training workers in proper methods of lifting.

Positioning the drill also exposes the miner to a risk of back injury. When positioning the drill, the miner must balance the tool while manipulating its orientation in space. This task results in the miner counteracting expected and unexpected forward and horizontal moments created by the drill. Counteracting unexpected forces during attempts to catch falling drills is a likely mechanism of injury. Narratives have shown that over 12% of the trunk exertion injuries occur when miners attempt to prevent drills from falling. Research by Marras, Rangarajulu, and Lavender (1987) has shown that the loading on the back increases dramatically when unexpected loads are experienced. Again, providing an additional handle on the tool would be expected to allow better control and reduce the possibility of experiencing these large unexpected loads.

Collaring the drill hole requires the miner to assume static work positions while exerting large trunk forces in order to support the drill. These large static forces are known to reduce the available strength of the worker on repeated collaring attempts. Hence, as the workday progresses and fatigue sets in, workers are forced to collar the drill hole with less available strength capacity (Astrand & Rodahl, 1977; Chaffin & Andersson, 1984). This situation increases the probability of a musculoskeletal injury. Variations in methods may be used to minimize the amount of static strength required to perform this operation.

The final drilling task that has contributed to back injuries in the drill operator involves drill removal. The narratives indicate that over 30% of the exertion injuries occur during the removal of the drill steel from the hole. Video-taped observations of this task reveal that a jerking movement is used to remove the drill in one to three motions. When lower holes are drilled, the risk of injury is increased. When removing the drill steel from lower holes, it often becomes stuck in the flushings. This situation can also lead to increased back strain due to an unexpected element of loading. In addition, low holes require more strength and place larger loads on the spine because the drill must be pulled upward during removal. Tool design changes and accompanying changes in handling methods may minimize the risk of injury due to this task.

In-depth analyses of the scaling operation have also shown how this tool can lead to lower back disorders. The center of mass of this tool is usually forward of the worker, thus creating a moment about the lumbar spine. This situation requires significant back muscle contraction and results in a high loading of the lower back. When this back loading is combined with severe jarring caused by the scaling bar contacting a hard surface, there is an increased risk of a lower back disorder. Change in tool design and method of use may reduce these excessive exertion risks. For example, the scaling bar may be counterbalanced so that the center of gravity of the tool is closer to the worker's body. Changes in method can include changes in arm position that would lower the arms and thereby minimize the loading on the lumbar spine.

SUMMARY

This analysis has identified the hand tools used in underground MNM mining that are involved in a significant number of accidents. The jackleg drill and the scaling bar are responsible for over 70% of all lost-time hand tool-related injuries and nearly 85% of the corresponding lost workdays. Accident sequences with greater probability and higher severity have been focused on in order to identify the key problem areas. The in-depth analysis techniques, such as underground task analysis, worker interviews, review of accident narratives, and ergonomic analysis of tool use, have suggested several hypotheses for design changes. These changes can be incorporated into the designs of both tools to help reduce the excessive muscular exertions that are required to use them, thereby decreasing the likelihood of exertion injuries. In addition, suggestions can be made to the workers regarding the methods of using these two tools. Correct lifting, handling, and supporting techniques will let the worker use the tools' weight and mass to accomplish the work task without undue risk of injury. Before these suggestions and design changes are implemented, however, they should be tested empirically to determine their effectiveness.

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