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AN ANALYSIS OF HAND TOOL INJURIES IN THE UNDERGROUND MINING INDUSTRIES

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16. Abstract (Limit: 200 words)

The objectives of this research were: 1) to identify the most hazardous powered and non-powered hand tools used in the underground mining industries (coal, metal, and nonmetal mines); 2) to determine the activities and tool use components associated with the injuries; 3) to use task and ergonomic analyses of the tool use to identify the components of the work that are associated with the injuries; and 4) to investigate ergonomic aspects of the injury and recommend methods to minimize the risk of injury due to tool use. This research was supported by the U.S. Bureau of Mines.

The analysis of a hand tool injury data base indicated that underground hand tool use injuries frequently involved over-exertion injuries to the back. Underground observations of tool use and the subsequent ergonomic analyses identified the components of the tool use sequence which would most likely result in an injury. Biomechanical laboratory studies were performed to understand the nature of the trunk's reaction and the subsequent spine loading due to the use of these tools. Recommendations regarding the tool designs and methods of use have been suggested.

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AN ANALYSIS OF HAND TOOL INJURIES IN THE UNDERGROUND MINING INDUSTRIES

by

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ABSTRACT

The objectives of this research were: 1) to identify the most hazardous powered and non-powered hand tools used in the underground mining industries (coal, metal, and nonmetal mines); 2) to determine the activities and tool-use components associated with the injuries; 3) to use task and ergonomic analyses of tool usage to identify the components of the work that are associated with the injuries; and, 4) to investigate ergonomic aspects of the injury and recommend methods to minimize the risk of injury due to tool use. This research was supported by the U.S. Bureau of Mines.

The analysis of a hand tool injury data base indicated that underground hand tool use injuries frequently involved overexertion injuries to the back. In underground coal mining, the use of the scaling bar, jack, and pry bar account for 47% of the lost-time handtool-related injuries. These same tools, however, account for slightly less than 68% of the corresponding lost work days. In underground metal-nonmetal mining, the use of the jackleg drill and the scaling bar are responsible for nearly 71% of the lost-time handtool-related injuries, and account for slightly less than 85% of the corresponding lost work days.

Underground observations of tool use and the subsequent ergonomic analyses identified the components of the tool use sequences that would most likely result in an injury. Biomechanical laboratory studies were performed to understand the nature of the trunk's reaction and the subsequent spine loading during the use of these tools. Recommendations regarding the tool designs and methods of use have been suggested.

CHAPTER 1: INTRODUCTION

Handtools have been in use by humans since prehistoric times. Presently, handtools are used regularly in most occupations and are commonly found in the home. Along with the many benefits of handtool use, injury risk also prevails. Ayoub, Purswell, and Hicks (1977) reviewed injury data and found that injuries resulting from handtool use were responsible for 5% to 10% of all compensable injuries. It was also concluded that 70% to 80% of these handtool injuries were due to non-powered tools.

It is also known that certain occupations are at a greater risk of handtool injury due to the nature of the occupation and the increased exposure to tool use. For example, Rockwell (1982) has reported that handtool injuries were responsible for a total of 10 of all on-the-job injuries in the rail industry, resulting in 3 to 4 million lost worker-hours per year. Similarly, the mining industry represents an environment that has a high risk of injury due to hand tool use.

It is known that hand tool use and misuse contributes substantially to the toll of non-fatal injuries in underground mining. For example, in 1981 MSHA classified 62 of 2008 non-fatal lost time accidents occurring in underground metal mines as "hand tool" accidents. In the same year, 880 of 12,187 lost-time and 392 of 1899 no-days-lost accidents in underground coal mines were so classified. It is also believed that many other accidents labeled as "slips and falls", "electrical", or "slips and bumps" may really be due, either directly or indirectly, to hand tool use. Thus, the effective lost time and no-lost-time accident rate due to hand tool use may be greater than generally realized.

Previous research efforts have identified hand tools used in underground mining as a problem area in need of further study. For example, a 1980 Perceptronics study revealed that two common hand tools, the scaling bar and the feedleg drill, required ergonomic assessment. The scaling operation was involved in 9.45% of the classifiable unit operations. Scaling is a hazardous task that places unusual biomechanical demands on the operator. It is a task that requires great operator skill, and is one for which little or no training is provided. Therefore, it was expected that an evaluation of the worker-tool interface would possess a significant potential for injury reduction. The feedleg drill was also suspected of causing injury to the workers. This tool, which is very large, heavy (100 to 120 lb), and awkward, is often used under less than ideal environmental conditions. It was expected that significant biomechanical risks are associated with the use of this tool, especially due to the workplace conditions in which the tool is used.

Biomechanical or ergonomic assessments and evaluations are believed to possess the potential for understanding and controlling hand tool problems in an environment such as underground mining. The logic behind biomechanical workplace investigations assumes that there are both internal and external forces acting on the body. The external loads are imposed on the body due to the weight and resistances offered by the object that is being handled. Internal forces, on the other hand, are restorative forces within the body which counteract these external forces. These internal forces consist of the muscles, ligaments, and other supporting structures within the body that are usually affected by cumulative or repetitive trauma. However, due to the close proximity of these structures to the joint, compared to the location of the external force relative to the joint, the magnitude of the internal forces must be large to overcome their mechanical disadvantage. This is the root of most biomechanical and ergonomic problems associated with hand tool use.

The objective of this research was to perform a biomechanical and ergonomic assessment of hand tool use in underground mining. The specific aims were to identify those tools that were associated with the greatest risk of injury and to evaluate this increased risk in light of ergonomic principles. It is believed that this procedure would facilitate design recommendations and ameliorate injury.

This assessment took place via several steps:

(1) An epidemiological evaluation was performed that determined the circumstances of risk associated with each handtool used in underground mining. This assessment used a six-year data base of injury records from the underground mining industry to determine the sequence of events that occurred in handtool-related accidents. This evaluation helped identify those tools, tasks, and circumstances of injury that were associated with the various injury risks in underground mining.

(2) The high-risk task and tool sequences were observed underground in a sample of mines across the country.

(3) A task analysis was performed for each high-risk tool and sequence of injury components observed in the field observation stage.

(4) The components of the task analysis were compared with established ergonomic principles.

(5) Hypotheses were generated which were believed to address the ergonomic problems identified with the high-risk tools.

(6) A laboratory analysis was performed for the high-risk tools to determine the status of the internal forces of the body in relation to suggested recommendations.

Through this approach, a better understanding of the factors involved in handtool-related injuries in the underground mining environment was obtained. It is believed that if the knowledge and recommendations presented in this report are applied to handtool usage design and the working environment, the risk of injury associated with the use of these tools will be reduced.

CHAPTER 2: EPIDEMIOLOGY

INTRODUCTION

Objective

The objective of this project phase was to review existing underground mining handtool data to gain an understanding of how tool use relates to injury. Generally, this exposure metric identification focused upon identifying the scope, exposure, and risk of injury associated with handtool uses. In order to accomplish this goal, several steps were necessary. First, the magnitude of handtool injury problems had to be assessed. Injury magnitude was assessed by considering both the frequency and severity of injury. Second, it was necessary to determine what handtools and the degree that each handtool contributed to the overall problem. Next, the ergonomic components of handtool injury were objectively assessed. Finally, the probable source of the injury components were identified for each tool.

Approach

The general approach to achieve these objectives can be described as "funnel shaped" using several steps. First, a broad review of the handtool population in underground mining was made. This broad view included both a review of tools made available from manufacturers, as well as a review of the various types of tools actually used in the mines. Second, a data base was reviewed so that the tools that were associated with significant injury rates could be identified. This review was conducted as a function of individual years, as well as a function of the cumulative total for the 6 years studied. Third, the data base was further analyzed so that the association between the components of tool injury, nature of injury, type of injury, and part of body injured could be evaluated. Fourth, these components were linked to each other according to their conditional probability. This facilitated a probabilistic view of the sequence of components involved in a handtool injury. Next, the project's efforts were further refined so that the focus was upon the sequence of components that were involved in the greatest risk of handtool injury. Finally, scenarios were developed that related the sequence of handtool injury components to areas of ergonomic assessment focus. A flow chart of this approach is shown in Figure 2-1.

In this manner, a broad view of the hand tool problems lead to a refined focus upon the significant factors of hand tool use. This process also identifies the area of greatest potential for overall reduction of injury risk due to mining hand tool use.

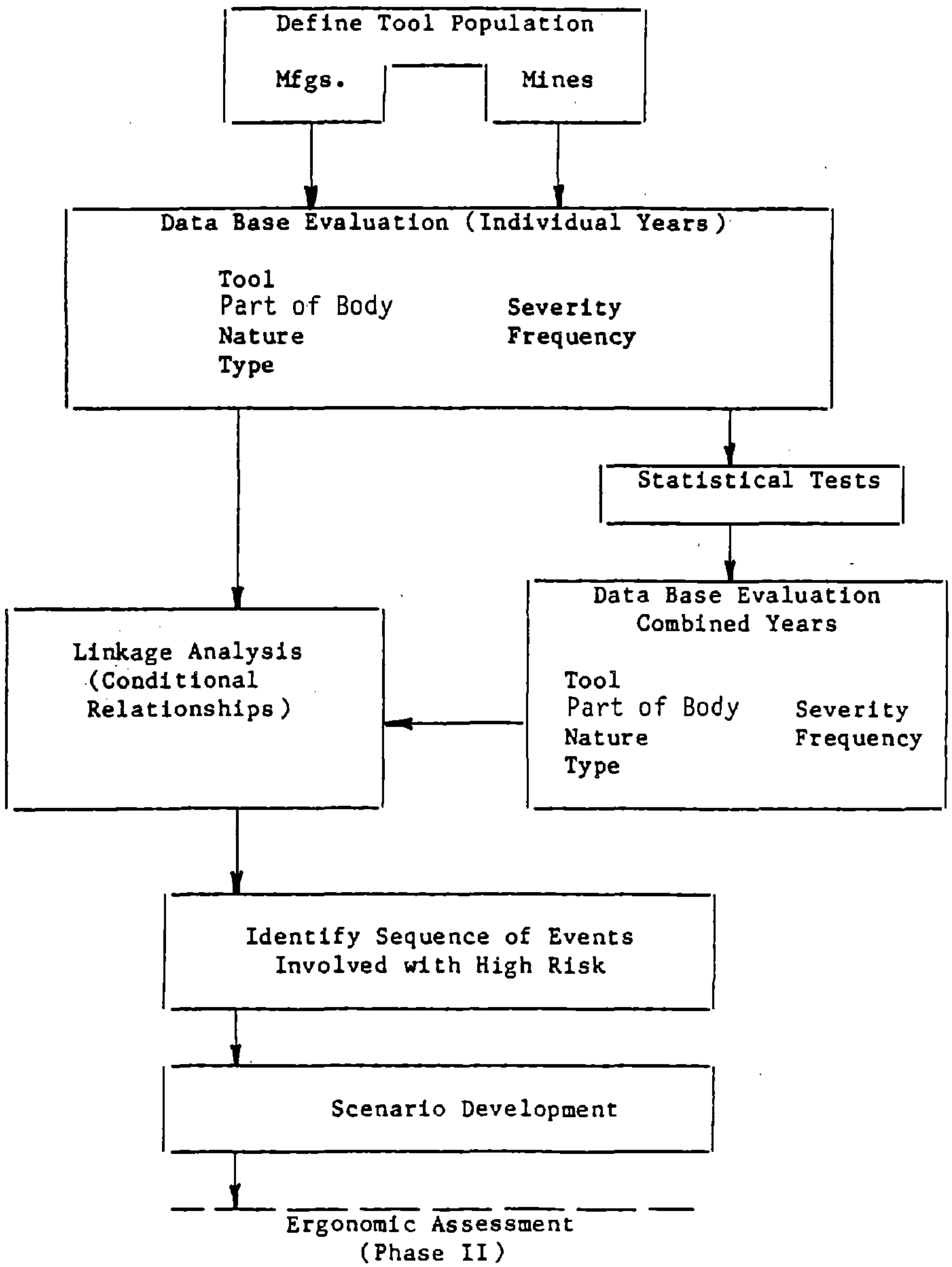


Figure 2-1: Flow chart of analysis approach for the epidemiological study.

METHODOLOGY

Tool Population

One of the initial tasks in attempting to assess handtool usage risks in underground coal, metal, and nonmetal mining was to define the available handtool population. In order to accomplish this task several approaches were used.

First, manufacturers of underground mining handtools were contacted by mail and phone. Manufacturers of tools used specifically in the mining industry were contacted and were asked for information describing the types and models of tools manufactured, the sales of each type of tool, the types of mining operations that use the tool, and safety instructions for use of the tools. The manufacturers were also asked about tool design, any ergonomic considerations, and redesign-modification history of each tool. These requests resulted in a fairly good response (about 50% response rate) and the subsequent compilation of tools available to underground miners. However, requests for design and sales information were usually unanswered.

Second, data bases were used to define the available tool population. The data base of the Mine Safety and Health Administration's (MSHA) Safety and Health Technology Center (formerly the Health and Safety Analysis Center) was reviewed to define the range and types of tools that were used and implicated in handtool injury accidents. This review was of marginal value for defining the underground tool population since most tools are placed into categorical definitions for the purposes of the data analysis, and many of the narrative descriptions of accidents from the MSHA Form 7000-1 are not very explicit.

Finally, the tool population used by the mines was evaluated. A sampling of mines was accomplished through a personal data collection technique so that unique tools, worker-modified tools, and the relative mix of standard tools available from manufacturers could be evaluated.

Data Base Evaluation Methodology

The major task in Phase I consisted of the collection of relevant hand tool injury information through a review of the available data bases related to injuries associated with handtool usage. Several potential sources of data were contacted. These sources included the Liberty Mutual Insurance Company, the Consolidation Coal Company, the United Mine Workers Union, several small insurance companies specializing in mine insurance, Worker's Compensation, National Coal Association, National Commission of Compensation Insurance, National Association of Manufacturers, National Welfare and Retirement Fund, National Coalition of Blacklung and Respiratory Disease Clinics, National Institute of Occupational Safety and Health, the Hand Tool Institute, as well as many other sources. A few of these sources did have data on handtool accidents; however, none of the data was computerized nor was it arranged so that it could be accessed according to the components of interest for handtool evaluation. An evaluation of these data was not feasible within the time constraints of this contract.

Although the MSHA data base did not provide any detailed information on the population of handtools in use in the underground mining industries, it did provide an excellent source of handtool-related injury information for the years 1978 through 1983. This data base was the most complete and well-documented source available for a quantitative evaluation of handtool-related injuries. The data base was thoroughly investigated and a methodology for handtool injury information extraction was developed. This methodology consisted of two stages. First, statistical evaluations were performed that identified the magnitude of the injury and the components of the injury. Second, conditional relationships were derived between the components of the injury so that an interpretation of causal relationships could be achieved. This analysis procedure was performed for each problem tool as a function of each year, as well as for all years (1978-1983) of the MSHA data base. The methodology involved in this analysis procedure will be reviewed.

Injury Components

Initially the components of a handtool injury were quantified as a function of the time period (year or years) of interest. Both accident frequency and severity of injury (days lost) were used as measures of performance in these analyses. Each tool was evaluated separately as a function of coal or metal-nonmetal mining. The components of injury were categorized as a function of the tool used during the injury, the part of the body injured, the nature of injury, and the type of accident. The category components are defined below:

1. Part of Body Components

The part of body classification identifies the part of the body injured. Usually there is only one part of the body reported with one nature of injury. If more than one part of body is reported with one nature of injury, coding is recorded as multiple. If there is more than one nature of injury and more than one part of body, the more serious nature of injury is accompanied by the part of body affected. For example: An amputation must be accompanied by part of body amputated and not coded as multiple parts of body. If, with multiple injuries, no determination can be made as to the most severe nature of injury, it is then coded multiple; if there are multiple parts of body injured, part of body coding is multiple also. This coding is broken down into the following components:

Head
Brain
Ear(s)
- Ear(s) external
- Ear(s) internal (include hearing)

Eye(s) (include optic nerves and vision)
Face
- Jaw (include chin)
- Mouth (include lips, teeth, tongue, throat, and sense of taste)
- Nose (include nasal passages, sinus, and sense of smell)
- Face, multiple parts (any combination of above parts)

Face, NEC (Not Elsewhere Classified)
Scalp
Skull
Head, multiple (any combination of above parts)
Head, NEC (include forehead and eyebrows)
Neck

Upper extremities
Arm(s) (above wrist)
Upper arm
Elbow
Forearm
Arm, multiple (any combination of above parts)
Arm, NEC
Wrist
Hand (not wrist or fingers)
Finger(s)
Upper extremities, multiple (any combination of above parts)
Upper extremities, NEC

Trunk
Abdomen (include internal organs), stomach, liver
Back (include back muscles, spine, and spinal cord)
Chest (include ribs, breast bone, and internal organs of the chest)
Hips (include pelvis, pelvic organs, and buttocks)
Shoulder(s)
Trunk, multiple (any combination of above parts)
Trunk, NEC (include side)

Lower Extremities
Leg(s) (above ankle)
Thigh
Knee
Lower leg
Leg, multiple (any combination of above parts)
Leg, NEC
Ankle
Foot (not ankle or toes)
Toe(s)
Lower extremities, multiple (any combination of above parts)
Lower extremities, NEC

Multiple Parts
Multiple parts (applies when more than one major body part has been affected, for example: an arm and a leg).

Body parts, NEC

2. Nature of Injury Components

The nature of injury classification identifies the injury in terms of its principal physical characteristics. As a general rule, the basic injury, not something that occurred later, is described. Below are rules for selection in cases of multiple injuries:

A. When one injury is obviously more severe than any of the others, that injury is selected. For example: an injury involving permanent impairment is selected in preference to a temporary injury, (i.e., select an amputated finger rather than a cut hand).

B. Where an individual suffers several injuries, such as cuts and sprains, and no one injury is indicated as more serious than any other, it is classified as "multiple injuries." Nature of injury is directly associated with part of body and source of injury for analytical purposes. Nature of injury involves the following events:

Amputation
Concussion -- brain, cerebral
Contagious or infectious disease -- anthrax, brucellosis, tuberculosis, pneumonia, etc.
Contusion, bruise -- intact skin surface
Crushing
Cut, laceration, puncture -- open wound
Dislocation
Dust in eyes
Electric shock, electrocution
Fracture, break, or chip -- for this project, a broken bone on a limb has been assumed by the contractor to include all parts of that limb (e.g., a break to the arm may include the upper arm, the forearm, or the fingers).
Hernia; rupture -- Include both inguinal and noninguinal hernias
Inflammation or irritation of joints, tendons, or muscles -- Include bursitis, synovitis, tenosynovitis, etc. Does not include strains, sprains, or dislocation of muscles or tendons.
Scratches, abrasions (superficial wounds)
Sprain, strains (include ruptured disc in back; whiplash; twisted part of body; torn knee cartilage)
Multiple injuries

3. Type of Accident Component

The accident type identifies the event that directly resulted in the reported injury. The accident type is directly related to the source of injury. This relationship must be maintained to permit accurate analysis. Particular care must be exercised to select the injury-producing event when the accident sequence comprises a series of associated events. Type of accident involves the following events:

Struck against stationary object
Struck against moving object
Struck by concussion
Struck by falling object
Struck by flying object
Struck by rolling (sliding) object
Struck by powered moving object
Struck by, NEC
Fall from machine, vehicle, or equipment
Fall to the walkway or working surface
Fall onto or against objects
Caught in, under, or between running or meshing objects
Caught in, under, or between moving and stationary objects
Caught in, under, or between two or more moving (not meshing) objects
Caught in, under, or between collapsing material or buildings
Caught in, under, or between, NEC
Overexertion in lifting objects
Overexertion in pulling or pushing objects
Overexertion in wielding (sledge hammer) or throwing objects
Overexertion, NEC

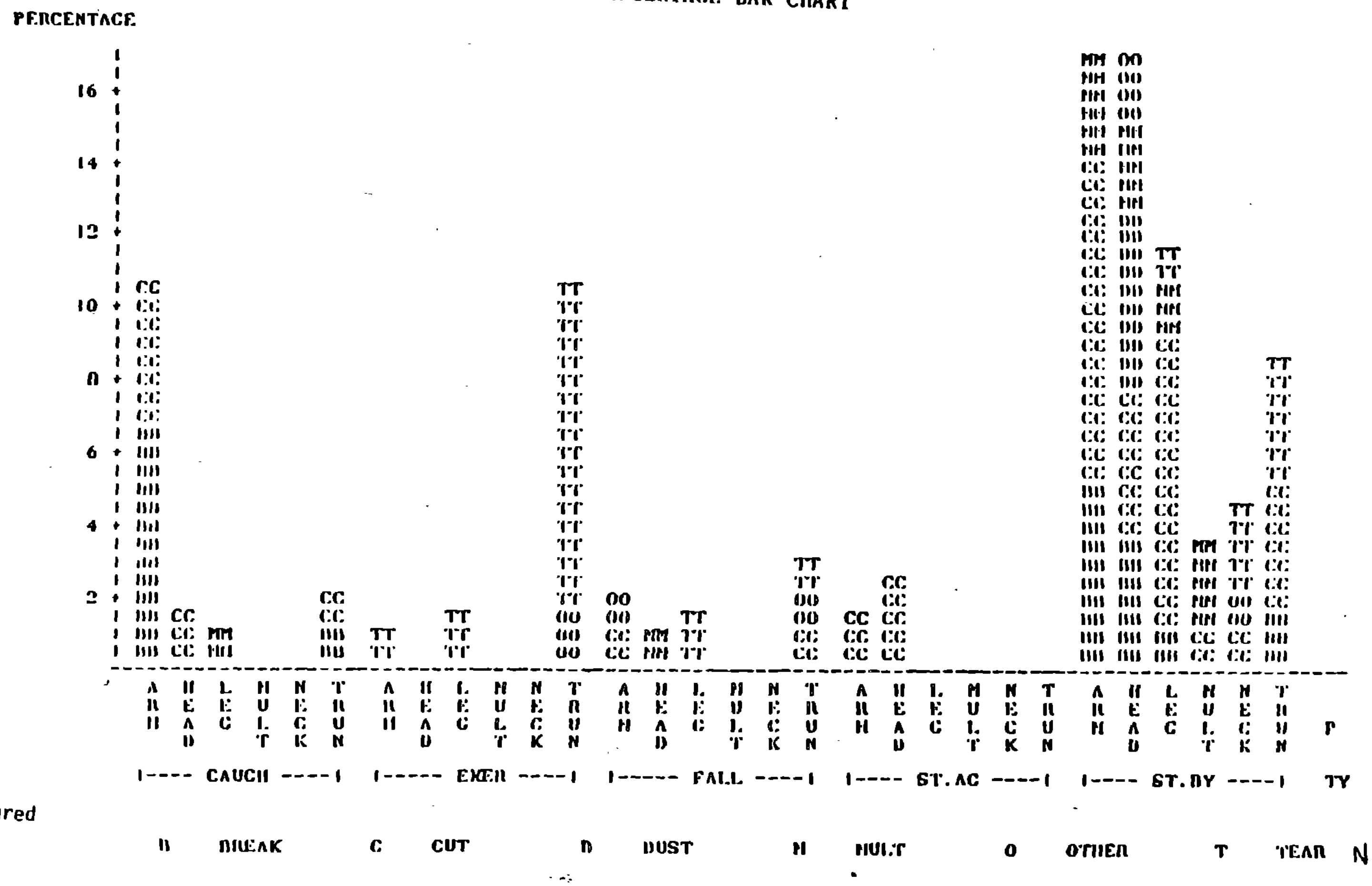
Injury Component Interaction

The interactions between the components of handtool accidents were investigated by several methods. Accident frequency, defined in terms of the percentage of all injuries for a particular tool over a given period of time (each year), was first evaluated. This interaction information was evaluated collectively as a function of part of body, nature of injury, and type of accident. For ease of interpretation, these interactions are reported graphically for each tool. An example of such a graphical representation of the data is shown in Figure 2-2.

This figure clearly shows the relationship between the components of the handtool injury. The abscissa of this figure represents the mix of injury components, whereas the ordinate represents the percentage of total frequency. The frequency of bar chart activity under the struck-by category indicates that a large percentage of accidents in the use of this tool were due to the operator being struck by an object. The relative area covered by the bars under the particular category in this plot quantifies the percentage of accidents that were due to this type of accident. Within each type of accident classification the accidents are further broken down into the part of body injured. The ordinate can be used to quantify this breakdown. For example, in figure 2-2, over 16% (the largest amount) of the accidents were due to an object striking the worker and injuring the arm or head.

Each bar within the plot further divides the accident into its components by quantifying the nature of injury. For example, of the injuries for the tool shown in Figure 2-2, over 6% were injuries to the arm due to the employee being struck by an object. Furthermore, by observing the individual symbols that make up each bar, we can conclude that about 1/3 of these injuries resulted in a break of the arm.

COAL PNEUMATIC DRILL ACCIDENTS IN 1980
YEAR = 80
PERCENTAGE BAR CHART



KEY
P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-2: Interaction between nature of injury and part of body affected for a single year (1980) and single tool (jack leg drill) as a function of injury frequency.

This technique facilitates a macroscopic view of the mix of injury components. It allows one to quickly identify and focus upon the components that represent potential problems.

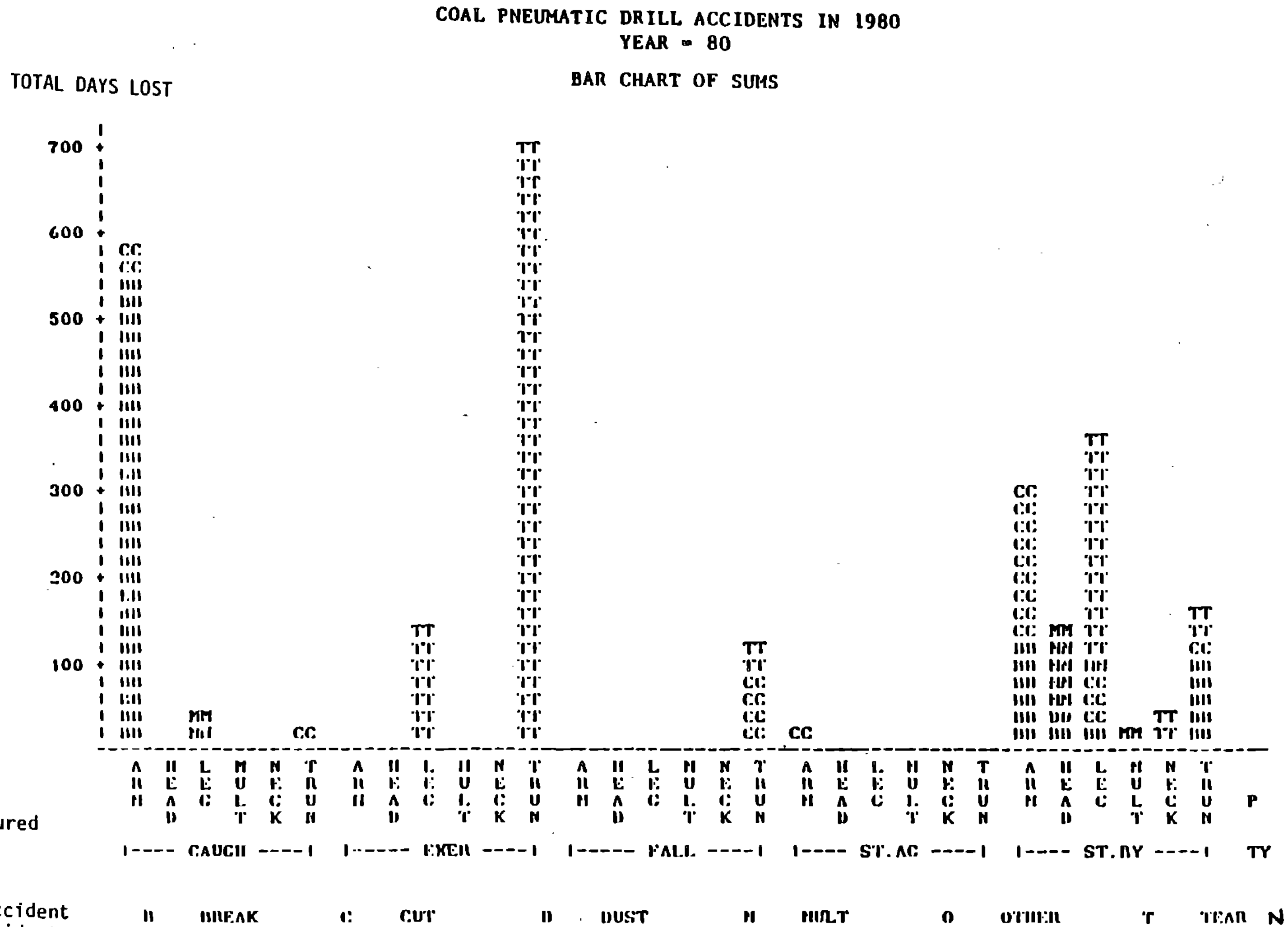
A similar analysis was also performed for each tool as a function of each year except the dependent measure was injury severity. Injury severity was defined as days lost due to the injury. This analysis was necessary since frequency may not show the true risk of an injury. A minor accident that occurs often may not result in a lot of lost time, but would be identified as a problem area. Likewise, a severe accident may occur infrequently and may not be identified as a problem area by observing frequency of accidents only. Therefore, statistical evaluations were performed for both frequency and total days lost.

Figure 2-3 shows an example of a bar chart analysis where the dependent measure was lost days. This figure represents the same tool and year as in Figure 2-2, however, exertion injuries to the trunk soft tissue (tears) now represent the largest problem (over 700 days lost), instead of struck-by injuries to the arm that were identified when the frequency of tool injury was investigated. Thus, both frequency and severity measures are important in a handtool analysis and provide different types of information.

These bar chart statistical analyses were used to evaluate the data as a function of each year and cumulative years for each tool. The data were also combined and evaluated for cumulative years when justified by chi-square analyses of individual years. This analysis provided a useful method to assess the overall mix of the components of handtool injury. However, more detailed information regarding the marginal and conditional statistics of each injury component was necessary for a complete analysis. This type of information was provided through the use of several other statistical techniques.

First, the type of injury was quantified. The areas in the bar charts represented this statistic; this information, however, was not directly quantifiable. Pie charts were used to quantify and display this information. Figure 2-4 shows an example of such a chart for the same tool and year data discussed previously. This figure clearly shows that 61.48% of injuries were due to struck-by accidents, whereas 13.11% were due to overexertions. Similar analyses were also available as a function of accident severity (days lost).

Next, the interaction between the nature of injury and the part of the body affected was examined while controlling for the type of injury as a function of frequency. An example of this analysis is shown in Table 2-1. This analysis shows that 81.25% of injuries were trunk injuries for this tool and 68.75% of injuries were injuries involving tearing (soft tissue trauma). This table shows frequency, percentage, nature, and part of body statistics, as well as marginal statistics. This table provides a means to truly isolate interactive statistics, as well as marginal statistics for each condition.

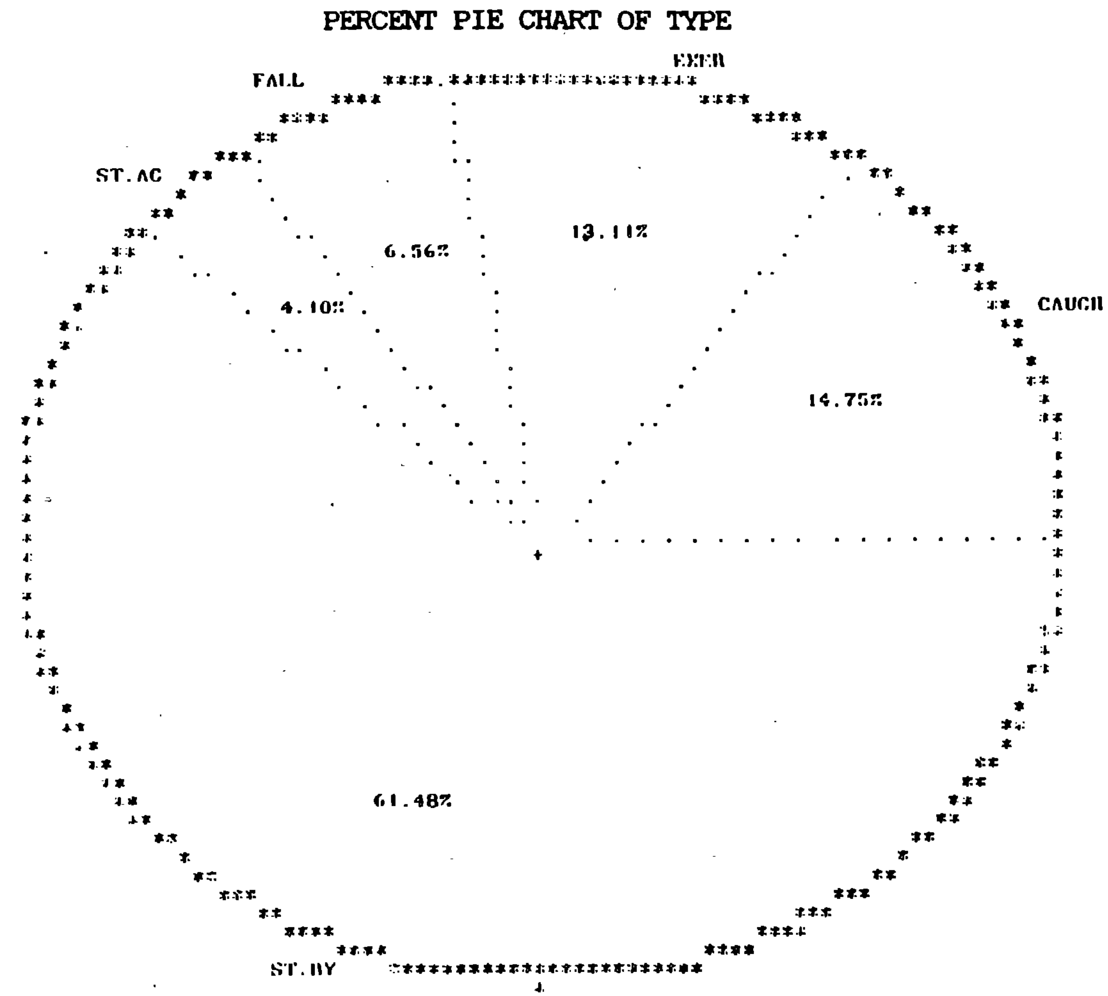


KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-3: Interaction between nature of injury and part of body affected for a single year (1980) and a single tool (jack leg drill) as a function of days lost.

COAL PNEUMATIC DRILL ACCIDENTS IN 1980
YEAR = 80



KEY

CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-4: Pie chart of type of injury.

Table 2-1: Marginal Statistics table for part of body and nature of injury for a jackleg drill during one year (1980)

COAL JACKLEG DRILL ACCIDENTS IN 1980

TABLE OF P BY N
CONTROLLING FOR TY=EXER

P / N FREQUENCY PERCENT ROW PCT COL PCT	BREAK	CUT	DUST	MULT	OTHER	TEAR	TOTAL
ARM	0 . . .	0 . . .	0 . . .	0 . . .	0 0.00 0.00 0.00	1 6.25 100.00 7.14	1 6.25
HEAD	0 . . .	0 . . .	0 . . .	0 . . .	0 . . .	0 . . .	0 0.00
LEG	0 . . .	0 . . .	0 . . .	0 . . .	0 0.00 0.00 0.00	2 12.50 100.00 14.29	2 12.50
MULT	0 . . .	0 . . .	0 . . .	0 . . .	0 . . .	0 . . .	0 0.00
NECK	0 . . .	0 . . .	0 . . .	0 . . .	0 . . .	0 . . .	0 0.00
TRUN	0 . . .	0 . . .	0 . . .	0 . . .	2 12.50 15.38 100.00	11 68.75 84.62 78.57	13 81.25
TOTAL	. .	. .	. .	. .	2 12.50	14 87.50	16 100.00

KEY

P	Part of body injured
N	Nature of injury
COL	Column
MULT	Multiple injuries Multiple body parts
TRUN	Trunk injury

Finally, the interaction between nature of injury and the part of body was evaluated while controlling for injury type as a function of severity (average days lost). This analysis was performed using bar charts as shown in Figure 2-5. These figures also indicate frequency of injury, as well as average days lost. For example, most exertion injuries for pneumatic drills were due to tears. Of the tears, 2 injuries involved the leg with an average loss of 74 days, whereas there were 11 trunk injuries with average losses of 64 days. This analysis provided still another way to evaluate the interaction between injury components.

These various statistical analyses were used in concert for each individual year, as well as for combined years (where justified via statistical tests) to quantify the components of handtool injury. This analysis provided a broad overview of injuries and permitted the quantification and identification of those areas that represented the largest problems among handtool users.

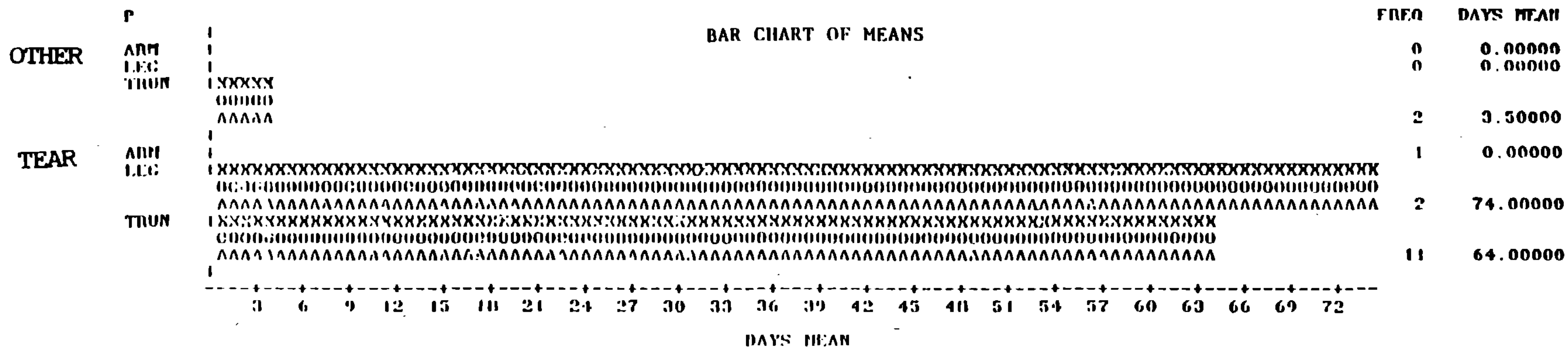
<u>Conditional Relationships</u>

A mechanism was needed to evaluate the sequence of component events that occur during handtool accidents so that the potential for risk reduction through ergonomic improvements could be assessed. To work towards this goal, the conditional relationships between the injury components were evaluated.

The conditional relationships between the injury components were evaluated by developing tree-branching diagrams. The injury-component statistics were used to develop tree-branching diagrams for each tool as a function of each year and as a function of cumulative years. An example of such a diagram is shown in Figure 2-6. This diagram shows the average number of days lost as a function of injury components and the probability of each combination of components occurring.

For the tool indicated in Figure 2-6 (a pneumatic drill used in the underground coal mining industry), there were 122 accidents in 1980 (this is provided in the title) which yielded an average loss of 22.2 days per incident (this is listed at the end of the figure). Following the upper branch of this tree shows that 14.8% (0.148) of the accidents (18 accidents with a mean of 37.1 days lost) were due to being caught while using the tool. Thirteen of these caught accidents (72.2% or, as shown, 0.722) resulted in injuries to the arm. Following the branch further to the right reveals that eight of the arm accidents involved a break (61.5% of the arm injuries). This conditional probability is further refined in the last probability (PR) column which indicates that 6.56% (0.0656) of all accidents for this tool in 1980 resulted in a catching-type accident that resulted in a broken arm. These accidents resulted in an average loss of 68.63 days. Thus, these 8 accidents resulted in a total of 549 days lost. The total days lost (TDL) for the arm due to caught-type accidents (in 1980 and involving a coal pneumatic drill) was 596. The other 47 days lost (596 minus 549) that involved a caught-type accident to the arm were caused by the 5 cut injuries that resulted in an average of 9.4 days lost per incident. The other branches of the tree are interpreted in a similar manner.

COAL PNEUMATIC DRILL ACCIDENTS IN 1980
TY = EXER



P	Part pf body injured
TY	Type of injury
EXER	Exertion-type of injury
Trun	Trunk injury
FREQ	No. of injuries related to this body part
MEAN	Avg. no. of days lost time

Figure 2-5: Interaction of nature of injury, part of body frequency and mean days lost for the coal jack leg drill.

FIGURE 2-6: Tree diagram of pneumatic drill accidents in coal mines for 1980 (N = 122).

```
CAUGHT  N= 18  (0.148)
TDL=  668  MEAN= 37.11
                        ARM     N= 13  (  0.722)
                        TDL=  596  MEAN= 45.85
                                        BREAK   N=  8  (0.615)  PR=0.0656    DAYS LOST=  68.63
                                        CUT     N=  5  (0.385)  PR=0.0410    DAYS LOST=   9.40
                        HEAD    N=  2  (0.111)
                        TDL=    1  MEAN=  0.50
                                        CUT     N=  2  (1.000)  PR=0.0164    DAYS LOST=   0.50
                        LEG     N=  1  (0.056)
                        TDL=   40  MEAN= 40.00
                                        MULT    N=  1  (1.000)  PR=0.0082    DAYS LOST=  40.00
                        TRUNK N=  2  (0.111)
                        TDL=   31  MEAN= 15.50
                                        BREAK   N=  1  (0.500)  PR=0.0002    DAYS LOST=   5.00
                                        CUT     N=  1  (0.500)  PR=0.0002    DAYS LOST=  26.00
EXERTION  N= 16  (0.131)
TDL=  859  MEAN= 53.69
                        ARM     N=  1  (  0.063)
                        TDL=    0  MEAN=  0.00
                                        TEAR    N=  1  (1.000)  PR=0.0082    DAYS LOST=   0.00
                        LEG     N=  2  (0.125)
                        TDL=  148  MEAN= 74.00
                                        TEAR    N=  2  (1.000)  PR=0.0164    DAYS LOST=  74.00
                        TRUNK N= 13  (0.813)
                        TDL=  711  MEAN= 54.69
                                        OTHER   N=  2  (0.154)  PR=0.0164    DAYS LOST=   3.50
                                        TEAR    N= 11  (0.046)  PR=0.0902    DAYS LOST=  64.00
FAIL N=  8  (0.066)
TDL=  129  MEAN= 16.13
                        ARM     N=  2  (  0.250)
                        TDL=    0  MEAN=  0.00
                                        CUT     N=  1  (0.500)  PR=0.0082    DAYS LOST=   0.00
                                        OTHER   N=  1  (0.500)  PR=0.0082    DAYS LOST=   0.00
                        HEAD    N=  1  (0.125)
                        TDL=    0  MEAN=  0.00
                                        MULT    N=  1  (1.000)  PR=0.0082    DAYS LOST=   0.00
                        LEG     N=  2  (0.250)
                        TDL=    3  MEAN=  1.50
                                        TEAR    N=  2  (1.000)  PR=0.0164    DAYS LOST=   1.50
                        TRUNK N=  3  (0.375)
                        TDL=  126  MEAN= 42.00
                                        CUT     N=  1  (0.333)  PR=0.0082    DAYS LOST=  82.00
                                        OTHER   N=  1  (0.333)  PR=0.0082    DAYS LOST=   6.00
                                        TEAR    N=  1  (0.333)  PR=0.0002    DAYS LOST=  38.00
STAG N=  5  (0.041)
TDL=   26  MEAN=  5.20
                        ARM     N=  2  (  0.400)
                        TDL=   20  MEAN= 10.00
                                        CUT     N=  2  (1.000)  PR=0.0164    DAYS LOST=  10.00
                        HEAD    N=  3  (0.600)
                        TDL=    6  MEAN=  2.00
                                        CUT     N=  3  (1.000)  PR=0.0246    DAYS LOST=   2.00
STBY N= 75  (0.615)
TDL= 1029  MEAN= 13.72
                        ARM     N= 21  (  0.280)
                        TDL=  298  MEAN= 14.19
                                        BREAK   N=  6  (0.206)  PR=0.0492    DAYS LOST=  10.50
                                        CUT     N= 11  (0.524)  PR=0.0902    DAYS LOST=  16.27
                                        MULT    N=  4  (0.190)  PR=0.0320    DAYS LOST=   2.00
```

KEY to abbreviations at end of figure.

```
HEAD   N= 21  (0.280)
TDL=  149  MEAN=  7.10
                     BREAK   N=  4   (0.190)  PR=0.0328    DAYS LOST=   4.25
                     CUT     N=  5   (0.238)  PR=0.0410    DAYS LOST=   1.60
                     DUST    N=  6   (0.206)  PR=0.0492    DAYS LOST=   2.67
                     MULT    N=  3   (0.143)  PR=0.0246    DAYS LOST=  33.67
                     OTHER   N=  3   (0.143)  PR=0.0246    DAYS LOST=   2.33
LEG    N= 14  (0.187)
TDL=  363  MEAN= 25.93
                     BREAK   N=  1   (0.071)  PR=0.0082    DAYS LOST=  22.00
                     CUT     N= 10   (0.714)  PR=0.0028    DAYS LOST=   6.30
                     MULT    N=  2   (0.143)  PR=0.0164    DAYS LOST=   6.00
                     TEAR    N=  1   (0.071)  PR=0.0082    DAYS LOST= 266.00
MULT   N=  4  (0.053)
TDL=   14  MEAN=  3.50
                     CUT     N=  1   (0.250)  PR=0.0082    DAYS LOST=   2.00
                     MULT    N=  3   (0.750)  PR=0.0246    DAYS LOST=   4.00
NECK   N=  5  (0.067)
TDL=   47  MEAN=  9.40
                     CUT     N=  1   (0.200)  PR=0.0082    DAYS LOST=   3.00
                     OTHER   N=  1   (0.200)  PR=0.0082    DAYS LOST=   0.00
                     TEAR    N=  3   (0.600)  PR=0.0246    DAYS LOST=  14.67
TRUNK  N= 10  (0.133)
TDL=  150  MEAN= 15.00
                     BREAK   N=  2   (0.200)  PR=0.0164    DAYS LOST=  53.50
                     CUT     N=  4   (0.400)  PR=0.0328    DAYS LOST=   2.50
                     TEAR    N=  4   (0.400)  PR=0.0120    DAYS LOST=  10.25

TOTAL   DAYS   LOST   =   2711

AVERAGE DAYS   LOST   =  22.221
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

This tree diagram represents all accident component sequences reported in the MSHA data base for that tool in that year of interest. A similar analysis was performed for each tool for each year (1978 to 1983), and for each tool over the cumulative years.

Scenario Development

The statistical component information and the conditional relationship information were used to develop accident scenarios for each branch of the conditional relationship representing a significant risk of injury. These scenario assessments help to define the contribution of ergonomic variables in the causation of handtool injuries.

Table 2-2 shows the format of scenario assessment to help define the role or contribution of ergonomic variables in the occurrence of handtool injuries. The various scenarios corresponding to each branch of the conditional relationship trees are identified in the first column of the table. The possible contribution of the various ergonomic factors (environment, tool defects, design defects, physical defects, misuse via method, misuse via knowledge, etc.) are then identified. Much of this table input is derived from the MSHA narrative reports, personal data collection, experience, observation, and the phase II visits.

This procedure provides a systematic methodology to concentrate and identify the components of the handtool injury that have the greatest potential for injury and, thus, the greatest potential for risk reduction.

Table 2-2: Scenario Assessment Technique

	Role of Environment	Role of Tool Defects	Role of Design	Physical Defect	Role of Misuse (Method)	Role of Misuse (Knowledge)
Axe Scenario #1						
Axe Scenario #2						
Bar Scenario #1 Scaling						
Bar Scenario #2 Non-Scaling						
Jack Scenario #1						
Jack Scenario #2						

RESULTS

The analyses that have previously been described were performed as a function of each individual year of MSHA handtool data (1978-1983) for each tool. The objective of this research was to get a picture of the overall structure and magnitude of handtool accidents in underground coal and metal-nonmetal mining. Variations in data as a function of individual years may reflect yearly economic trends within the mining industries more than changes in the nature of handtool accidents. Therefore, so that a more accurate picture of the overall problem could be derived, the data were investigated both as a function of individual years and as a cumulative total of all years.

A statistical justification was required to combine the data from individual years into a combined analysis. Chi-square analyses were performed to test the independence of the data population from each individual year. These tests revealed that there was a statistical justification to combine and evaluate the data for the individual years for all handtools of interest. Thus, the combined data analysis represents an overall quantitative evaluation of the components of handtool injuries reported in the MSHA data base for the years 1978 through 1983.

For the purpose of this discussion, only the combined analyses will be reported since they are most representative of the overall handtool problem.

The discussion of methodology reviewed the steps involved in the statistical evaluation of the data. For the purposes of this presentation, the analysis for each tool will be summarized for the individual component analysis through the use of two bar charts that describe the components as a function of both percentage of accident frequency and days lost (accident severity). The relationship between component events for the combined year data will then be summarized with a conditional tree-branching diagram.

Since conditions of tool use may affect the exposure risk and nature of handtool accidents, the handtool data were also evaluated as a function of whether the data were categorized as a function of coal mining or metal-nonmetal mining. Therefore, the results that are reported in this evaluation will be presented as a function of both the category of mining (coal or metal-nonmetal) and the type of handtool that was involved in the accident.

A. Evaluation of Handtools in Coal Mining

Although there are a variety of tools used in underground coal mining, only a few of them contribute to injuries that result in lost work days. Mechanic's or electrician's tools may cause an injury, but they usually do not result in any lost time. Thus, the following seven tools will be discussed in terms of accident frequency and severity: (1) Pneumatic drill, (2) Roof and rib scaling bar, (3) Pry bar, (4) Axe and hammer, (5) Jack, (6) Knife, and (7) Wrench.

1. Pneumatic Drill (PD)

The components of PD accidents evaluated as a function of frequency and severity are summarized in Figures 2-7 and 2-8, respectively. These figures indicate that the frequency of injury with the PD is greatest due to struck-by accidents involving the arm, leg, head, and trunk. High frequencies are also found for exertion injuries to the trunk, and arms being caught. When severity is considered, caught arms, which result in breaks, are responsible for the most number of lost days, followed by overexertion of the trunk that results in muscle, tendon, or ligament tears.

Figure 2-9 shows the conditional relationship between the components of accident injury. This figure indicates the probability of injury in relation to the components of PD use. For example, a large number of cuts to the head result from struck-by injuries. The conditional relationship indicates that there is a 8.8% probability of suffering this type of injury given that the operator was injured using a pneumatic drill. Such analyses are invaluable when the focus of the underground mine visits are concerned.

2. Scaling Bar

The components of scaling bar accidents as a function of accident frequency and severity are summarized in Figures 2-10 and 2-11, respectively. Figure 2-10 indicates that almost 80% of all scaling bar accidents involve an object striking the worker. Over 30% of the time the leg is struck. This figure also shows that this type of accident usually results in cuts and breaks. The only other accident type that occurs with any regularity (12% of the time) is an exertion accident to the trunk. This type of accident usually involves tearing of the soft tissue. Figure 2-11 indicates that the lost time (severity) due to scaling bar accidents correlates well with the frequency of injury. Struck-by accidents resulted in 19,796 lost days, whereas exertion accidents resulted in 1,950 lost days. No other types of accidents occurred with any significant regularity.

The conditional relationships between the components of scaling bar accidents are shown in Figure 2-12. This figure indicates that if a scaling bar accident occurs, 16.7% of the time it will involve a struck-by type of accident that cuts the leg and results in an average of 14 lost days. Other major risks due to scaling involve struck-by accidents involving cut arms and broken legs, or exertion accidents to the trunk resulting in tears. Each of these types of accidents occurs about 10% of the time. Cut arms result in an average loss of 10 days, whereas breaks of the leg result in loses of over 55 days. Exertion injuries to the trunk also have a high cost in terms of lost time, averaging almost 18 days.

3. Pry Bar

Figures 2-13 and 2-14 graphically depict the risk associated with the various accident components in pry bar use as a function of frequency and severity, respectively. Figure 2-13 indicates that 51% of pry bar accidents involve the struck-by category, resulting in cuts to the arm, leg, or head. The remaining accidents involve exertion to the trunk tissue, or caught-type accidents resulting mainly in breaks and cuts to the arm. Figure 2-14 indicates that severity of pry bar accidents involves different trends. This figure indicates that the most severe problem in terms of lost days are clearly due to exertion injuries involving trunk tears.

The conditional relationships between injury components are shown in Figure 2-15. This figure demonstrates that the most intense risk in pry bar use relates to trunk exertions involving tears. There is about a 27% chance that this accident type will occur given that a bar injury happened. These types of injuries average a high number of lost days (28.2). The other type of injury that occurs with high probability (13.1 percent) is struck-by accidents to the head resulting in cuts. However, these accidents are usually not very severe, averaging only 3.3 lost work days.

4. <u>Axe and Hammer</u>

Axe and hammer accidents were analyzed together since both tools involve striking tasks and have similar mechanisms of injury. Figure 2-16 provides the breakdown of component involvement as a function of accident frequency. This figure shows that the only accident that occurs with any frequency is the struck-by accident that involves breaks and cuts to the arm. Figure 2-17 indicates that these accidents are also responsible for a large number of lost days. However, this figure also shows that trunk exertions resulted in a substantial number of lost time (over 2000 days) over the six-year period.

The conditional relationships between the components of axe and hammer injuries are shown in Figure 2-18. This figure indicates that if an axe and hammer accident occurs, there is about an 8% chance that it will involve a trunk-exertion-tearing injury. These types of accidents have the highest severity cost of all axe and hammer injuries, over 24 lost days on the average. The probability of suffering a struck-by injury to the arm varies from 0.5% to almost 29% (see figure 2-18) depending on the type of injury incurred. The average lost time for these injuries varies from 6 to 19 days.

5. <u>Jack</u>

The components of jack injuries as a function of frequency and severity are displayed graphically in Figures 2-19 and 2-20, respectively. Figure 2-19 shows that the most frequently occurring injuries involve struck-by accidents involving breaks and cuts to the arm, head, and legs. Trunk exertions and caught arms also occur frequently. However, Figure 2-20 indicates that the severity of injury is by far the greatest when considering exertion injuries that involve tears to the trunk.

The relationship between the injury components of jack usage are apparent from the tree diagram shown in Figure 2-21. This figure indicates that a high risk of injury is due to trunk-exertion-tears (24.3% risk). This combination of components results in 29.8 mean lost days. Other high risks involve struck-by injuries to the arm, head, and leg. These risks vary greatly; however, unlike exertion injuries, this combination of components usually results in fewer mean lost days.

6. Knife

Knife injuries, as a function of frequency and severity, are shown in Figures 2-22 and 2-23, respectively. Both of these figures indicate that the major components of injury involve struck-by accidents resulting in cuts to the arm or leg.

Figure 2-24 shows the conditional relationship between the injury components. This figure indicates there is about a 71% risk of an arm cut due to a struck-by accident. In these instances, the mean lost days are 2.9 and 2.3 days for arm and leg injuries, respectively.

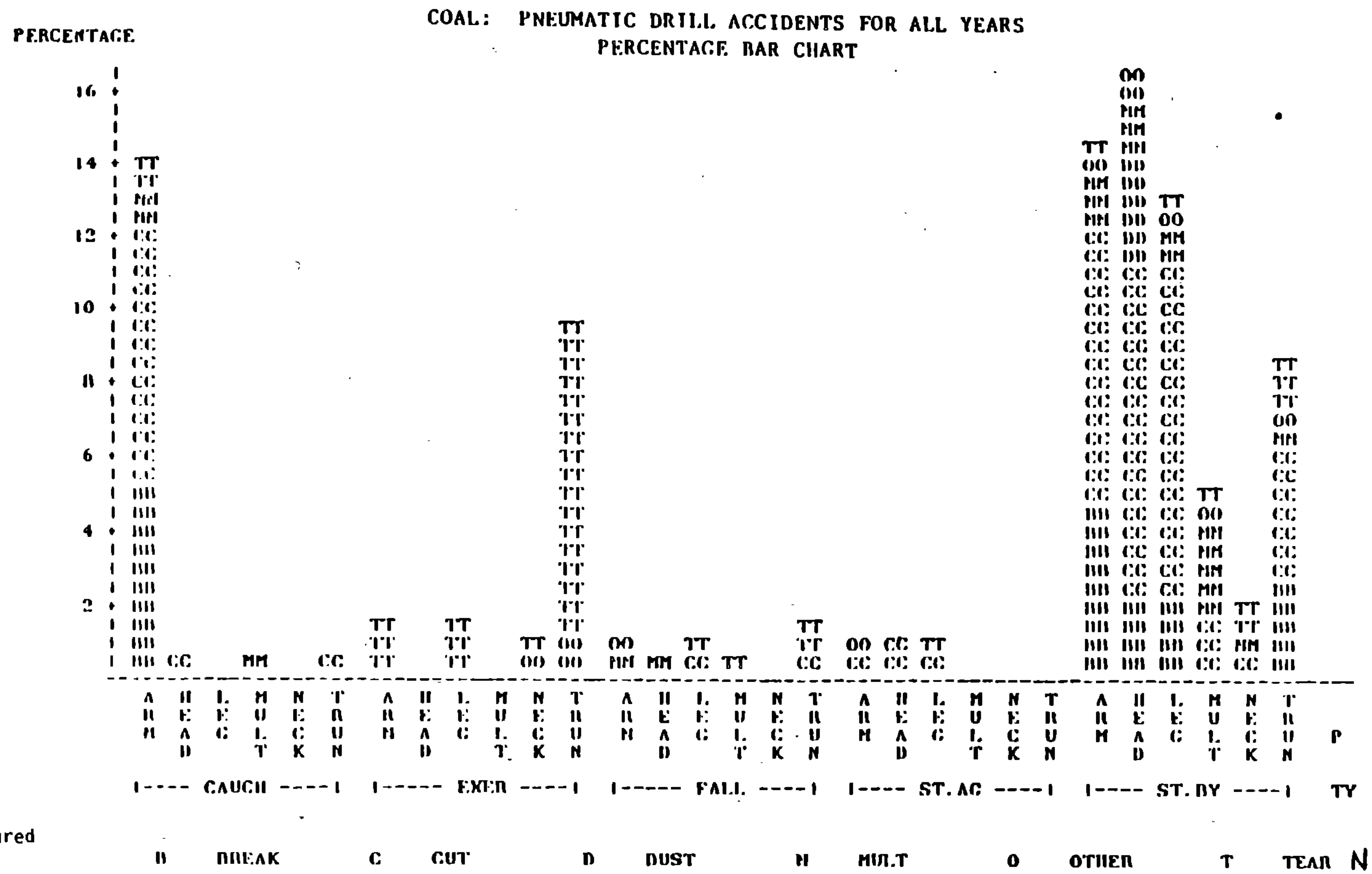
7. Wrench

The wrench was the only other tool involved in a significant number of injuries in underground coal mining. Figure 2-25 shows the percent of accident frequency associated with the various injury components. This figure indicates that struck-by injuries to the arm and head, and exertion injuries to the trunk each occurred about 25% of the time. Figure 2-26 shows the cost of these injuries in terms of total days lost. This figure indicates that the vast majority of lost days were due to exertion injuries resulting in tears to the trunk.

The relationship between these injury components is shown in the tree diagram in Figure 2-27. This figure indicates that there is a 23% (PR=0.2297) risk of injury due to trunk-tear-exertions. These injuries also result in a large severity (an average of 28.45 days lost for each of the 99 incidents). The combinations of struck-by accidents are shown to involve both lower frequency risks, as well as fewer average lost days.

SUMMARY

These statistics are discussed and summarized later in this chapter. Specifically, tables 2-3, 2-5, and 2-7, and figure 2-49 present an overview of the frequency and severity of handtool-related lost-time accidents that occurred in underground coal mining during 1978 to 1983.

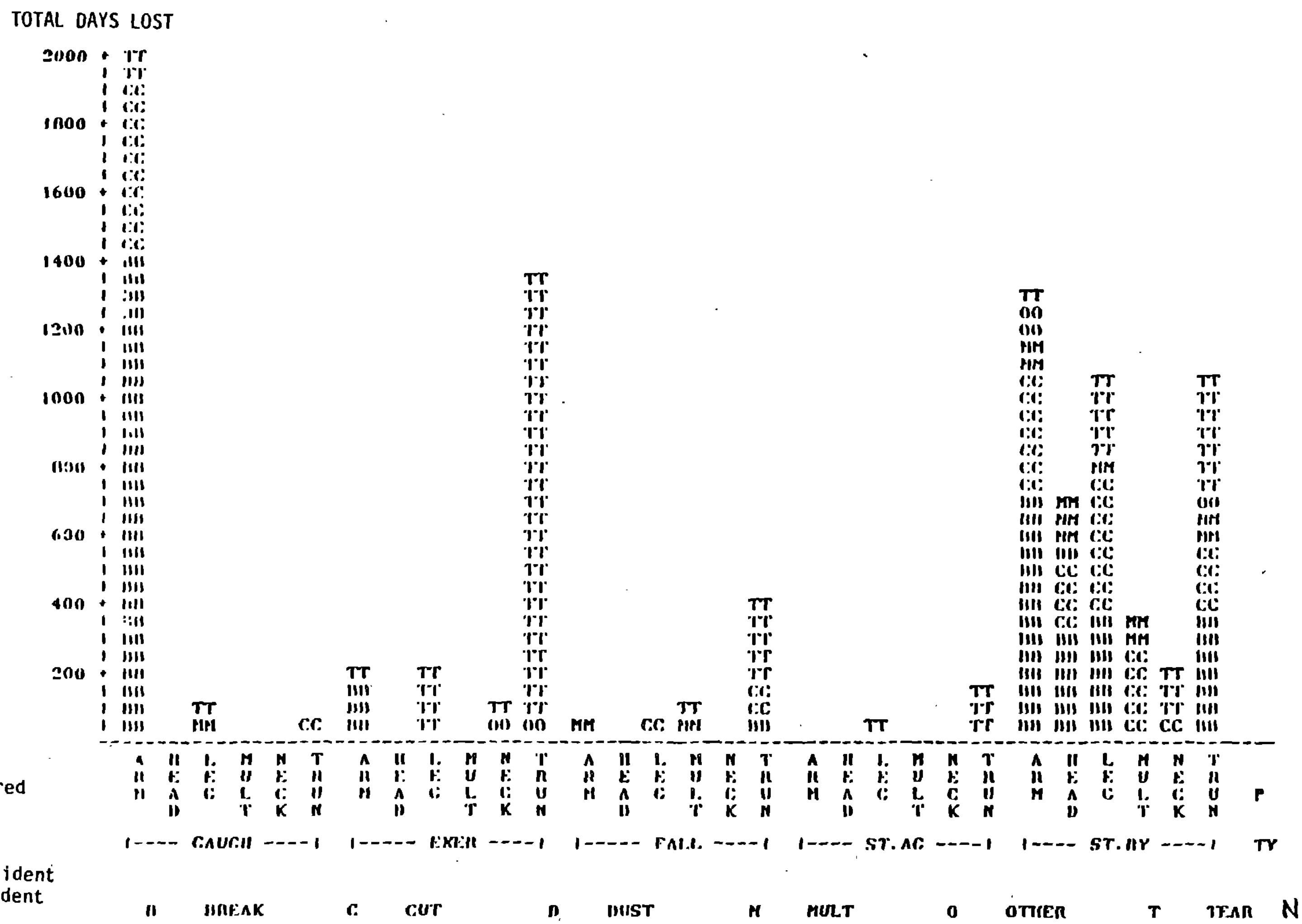


KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-7: Components of coal PD accidents as a function of frequency.

COAL: PNEUMATIC DRILL ACCIDENTS FOR ALL YEARS
BAR CHART OF SUMS



KEY
P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-8: Components of coal PD accidents as a function of days lost.

FIGURE 2-9: Tree diagram of pneumatic drill accidents in coal mines from 1978 to 1983 (N = 555).

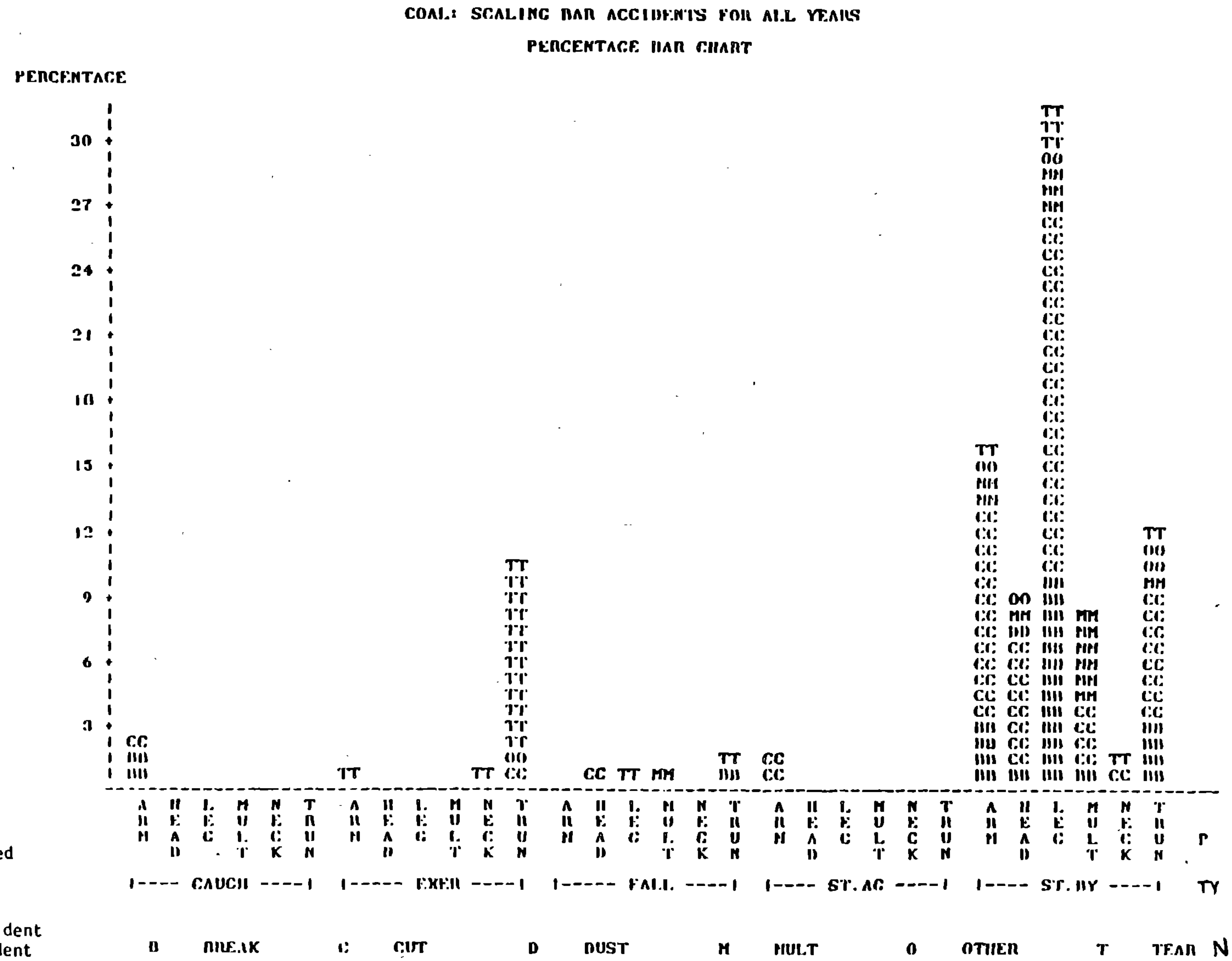
```
CAUGHT  N= 92  (0.166)
TDL= 2163  MEAN= 23.51
                    ARM     N= 80  (  0.870)
                    TDL= 2023  MEAN= 25.29
                                        BREAK   N= 20  (0.350)  PR=0.0505  DAYS LOST=  50.36
                                        CUT     N= 40  (0.500)  PR=0.0721  DAYS LOST=  11.00
                                        MULT    N=  5  (0.063)  PR=0.0090  DAYS LOST=   0.20
                                        OTHER   N=  1  (0.012)  PR=0.0010  DAYS LOST=   1.00
                                        TEAR    N=  6  (0.075)  PR=0.0108  DAYS LOST=  22.67
                    HEAD    N=  4  (0.043)
                    TDL=   17  MEAN=  4.25
                                        CUT     N=  3  (0.750)  PR=0.0054  DAYS LOST=   4.33
                                        MULT    N=  1  (0.250)  PR=0.0010  DAYS LOST=   4.00
                    LEG     N=  2  (0.022)
                    TDL=   74  MEAN= 37.00
                                        MULT    N=  1  (0.500)  PR=0.0018  DAYS LOST=  40.00
                                        TEAR    N=  1  (0.500)  PR=0.0018  DAYS LOST=  34.00
                    MULT    N=  2  (0.022)
                    TDL=   15  MEAN=  7.50
                                        MULT    N=  2  (1.000)  PR=0.0036  DAYS LOST=   7.50
                    TRUNK N=  4  (0.043)
                    TDL=   34  MEAN=  8.50
                                        BREAK   N=  1  (0.250)  PR=0.0018  DAYS LOST=   5.00
                                        CUT     N=  3  (0.750)  PR=0.0054  DAYS LOST=   9.67
EXERTION  N= 77  (0.139)
TDL= 1808  MEAN= 24.52
                    ARM     N= 11  (  0.143)
                    TDL=  232  MEAN= 21.09
                                        BREAK   N=  1  (0.091)  PR=0.0010  DAYS LOST= 166.00
                                        CUT     N=  1  (0.091)  PR=0.0010  DAYS LOST=   6.00
                                        MULT    N=  1  (0.091)  PR=0.0010  DAYS LOST=   0.00
                                        OTHER   N=  1  (0.091)  PR=0.0010  DAYS LOST=   0.00
                                        TEAR    N=  7  (0.636)  PR=0.0126  DAYS LOST=   0.57
                    LEG     N=  7  (0.091)
                    TDL=  206  MEAN= 29.43
                                        TEAR    N=  7  (1.000)  PR=0.0126  DAYS LOST=  29.43
                    MULT    N=  1  (0.013)
                    TDL=    0  MEAN=  0.00
                                        TEAR    N=  1  (1.000)  PR=0.0018  DAYS LOST=   0.00
                    NECK  N=  4  (0.052)
                    TDL=   83  MEAN= 20.75
                                        OTHER   N=  2  (0.500)  PR=0.0036  DAYS LOST=  28.00
                                        TEAR    N=  2  (0.500)  PR=0.0036  DAYS LOST=  13.50
                    TRUNK N= 54  (0.701)
                    TDL= 1367  MEAN= 25.31
                                        MULT    N=  1  (0.019)  PR=0.0018  DAYS LOST=   5.00
                                        OTHER   N=  6  (0.093)  PR=0.0090  DAYS LOST=  10.20
                                        TEAR    N= 40  (0.009)  PR=0.0065  DAYS LOST=  27.31
FALL N= 29  (0.052)
TDL=  595  MEAN= 20.52
                    ARM     N=  6  (  0.207)
                    TDL=   55  MEAN=  9.17
                                        CUT     N=  1  (0.167)  PR=0.0018  DAYS LOST=   0.00
                                        MULT    N=  2  (0.333)  PR=0.0036  DAYS LOST=  26.00
                                        OTHER   N=  2  (0.333)  PR=0.0036  DAYS LOST=   0.50
                                        TEAR    N=  1  (0.167)  PR=0.0018  DAYS LOST=   2.00
                    HEAD    N=  2  (0.069)
                    TDL=    0  MEAN=  0.00
                                        MULT    N=  2  (1.000)  PR=0.0036  DAYS LOST=   0.00
                    LEG     N=  7  (0.241)
                    TDL=   36  MEAN=  5.14
                                        CUT     N=  3  (0.429)  PR=0.0054  DAYS LOST=   9.67
```

```
                                         OTHER  N-  1  (0.143)  PR-0.0010    DAYS LOST-   0.00
                                         TEAR   N-  3  (0.429)  PR-0.0054    DAYS LOST-   2.33
                  MULT   N-  4  (0.130)
                  TOL-   95  MEAN- 23.76
                                         MULT   N-  1  (0.250)  PR-0.0018    DAYS LOST-  39.00
                                         OTHER  N-  1  (0.250)  PR-0.0010    DAYS LOST-   0.00
                                         TEAR   N-  2  (0.500)  PR-0.0036    DAYS LOST-  20.00
                  TRUNK N- 10  (0.345)
                  TOL-  409  MEAN- 40.90
                                         BREAK  N-  1  (0.100)  PR-0.0018    DAYS LOST-  51.00
                                         CUT    N-  3  (0.300)  PR-0.0054    DAYS LOST-  27.67
                                         OTHER  N-  1  (0.100)  PR-0.0010    DAYS LOST-   6.00
                                         TEAR   N-  5  (0.500)  PR-0.0090    DAYS LOST-  53.00
STAG N- 21  (0.038)
TOL-  317  MEAN- 15.10
                  ARM    N-  6  (  0.286)
                  TOL-   24  MEAN-  4.00
                                         CUT    N-  4  (0.667)  PR-0.0072    DAYS LOST-   5.00
                                         OTHER  N-  2  (0.333)  PR-0.0036    DAYS LOST-   2.00
                  HEAD   N-  6  (0.286)
                  TOL-   27  MEAN-  4.50
                                         CUT    N-  5  (0.833)  PR-0.0090    DAYS LOST-   1.40
                                         MULT   N-  1  (0.167)  PR-0.0010    DAYS LOST-  20.00
                  LEG    N-  5  (0.238)
                  TOL-   82  MEAN- 16.40
                                         CUT    N-  3  (0.600)  PR-0.0054    DAYS LOST-   5.33
                                         TEAR   N-  2  (0.400)  PR-0.0036    DAYS LOST-  33.00
                  NECK  N-  1  (0.048)
                  TOL-    1  MEAN-  1.00
                                         TEAR   N-  1  (1.000)  PR-0.0010    DAYS LOST-   1.00
                  TRUNK N-  3  (0.143)
                  TOL-  183  MEAN- 61.00
                                         CUT    N-  1  (0.333)  PR-0.0018    DAYS LOST-  12.00
                                         OTHER  N-  1  (0.333)  PR-0.0018    DAYS LOST-   0.00
                                         TEAR   N-  1  (0.333)  PR-0.0010    DAYS LOST- 171.00
STBY N- 336  (0.605)
TOL- 4754  MEAN- 14.15
                  ARM    N- 81  (  0.241)
                  TOL- 1304  MEAN- 16.10
                                         BREAK  N- 26  (0.321)  PR-0.0468    DAYS LOST-  27.01
                                         CUT    N- 43  (0.531)  PR-0.0775    DAYS LOST-   0.42
                                         MULT   N-  8  (0.099)  PR-0.0144    DAYS LOST-  11.00
                                         OTHER  N-  2  (0.025)  PR-0.0036    DAYS LOST-  43.00
                                         TEAR   N-  2  (0.025)  PR-0.0036    DAYS LOST-  19.00
                  HEAD   N- 91  (0.271)
                  TOL-  763  MEAN-  0.38
                                         BREAK  N- 10  (0.110)  PR-0.0180    DAYS LOST-  31.50
                                         CUT    N- 49  (0.538)  PR-0.0883    DAYS LOST-   4.20
                                         DUST   N- 17  (0.187)  PR-0.0306    DAYS LOST-   3.53
                                         MULT   N-  7  (0.077)  PR-0.0126    DAYS LOST-  24.14
                                         OTHER  N-  8  (0.000)  PR-0.0144    DAYS LOST-   1.63
                  LEG    N- 76  (0.226)
                  TOL- 1061  MEAN- 13.96
                                         BREAK  N- 12  (0.158)  PR-0.0216    DAYS LOST-  27.33
                                         CUT    N- 51  (0.671)  PR-0.0919    DAYS LOST-   7.71
                                         MULT   N-  5  (0.066)  PR-0.0090    DAYS LOST-  13.40
                                         OTHER  N-  4  (0.053)  PR-0.0072    DAYS LOST-   0.00
                                         TEAR   N-  4  (0.053)  PR-0.0072    DAYS LOST-  68.25
                  MULT   N- 27  (0.080)
                  TOL-  374  MEAN- 13.85
                                         BREAK  N-  1  (0.037)  PR-0.0018    DAYS LOST-   0.00
                                         CUT    N-  7  (0.259)  PR-0.0126    DAYS LOST-  34.71
                                         MULT   N- 13  (0.481)  PR-0.0234    DAYS LOST-   7.92
                                         OTHER  N-  4  (0.140)  PR-0.0072    DAYS LOST-   5.50
                                         TEAR   N-  2  (0.074)  PR-0.0036    DAYS LOST-   3.00
                  NECK  N- 13  (0.039)
```

```
TDL=  22Ø  MEAN= 16.92
                             CUT     N=  4  (Ø.3ØØ)  PR=Ø.ØØ72     DAYS LOST=  17.75
                             MULT    N=  2  (Ø.154)  PR=Ø.ØØ36     DAYS LOST=   9.5Ø
                             OTHER   N=  1  (Ø.Ø77)  PR=Ø.ØØ18     DAYS LOST=   Ø.ØØ
                             TEAR    N=  6  (Ø.462)  PR=Ø.Ø18Ø     DAYS LOST=  21.67
TRUNK N= 4Ø  (Ø.143)
TDL= 1Ø32  MEAN= 21.5Ø
                             BREAK   N= 13  (Ø.271)  PR=Ø.Ø234     DAYS LOST=  27.85
                             CUT     N= 19  (Ø.396)  PR=Ø.Ø342     DAYS LOST=   9.79
                             MULT    N=  4  (Ø.ØØ3)  PR=Ø.ØØ72     DAYS LOST=  23.75
                             OTHER   N=  3  (Ø.Ø63)  PR=Ø.ØØ54     DAYS LOST=  15.ØØ
                             TEAR    N=  9  (Ø.1ØØ)  PR=Ø.Ø162     DAYS LOST=  38.22
TOTAL  DAYS  LOST  =   9717

AVERAGE DAYS LOST  =  17.5ØØ
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)



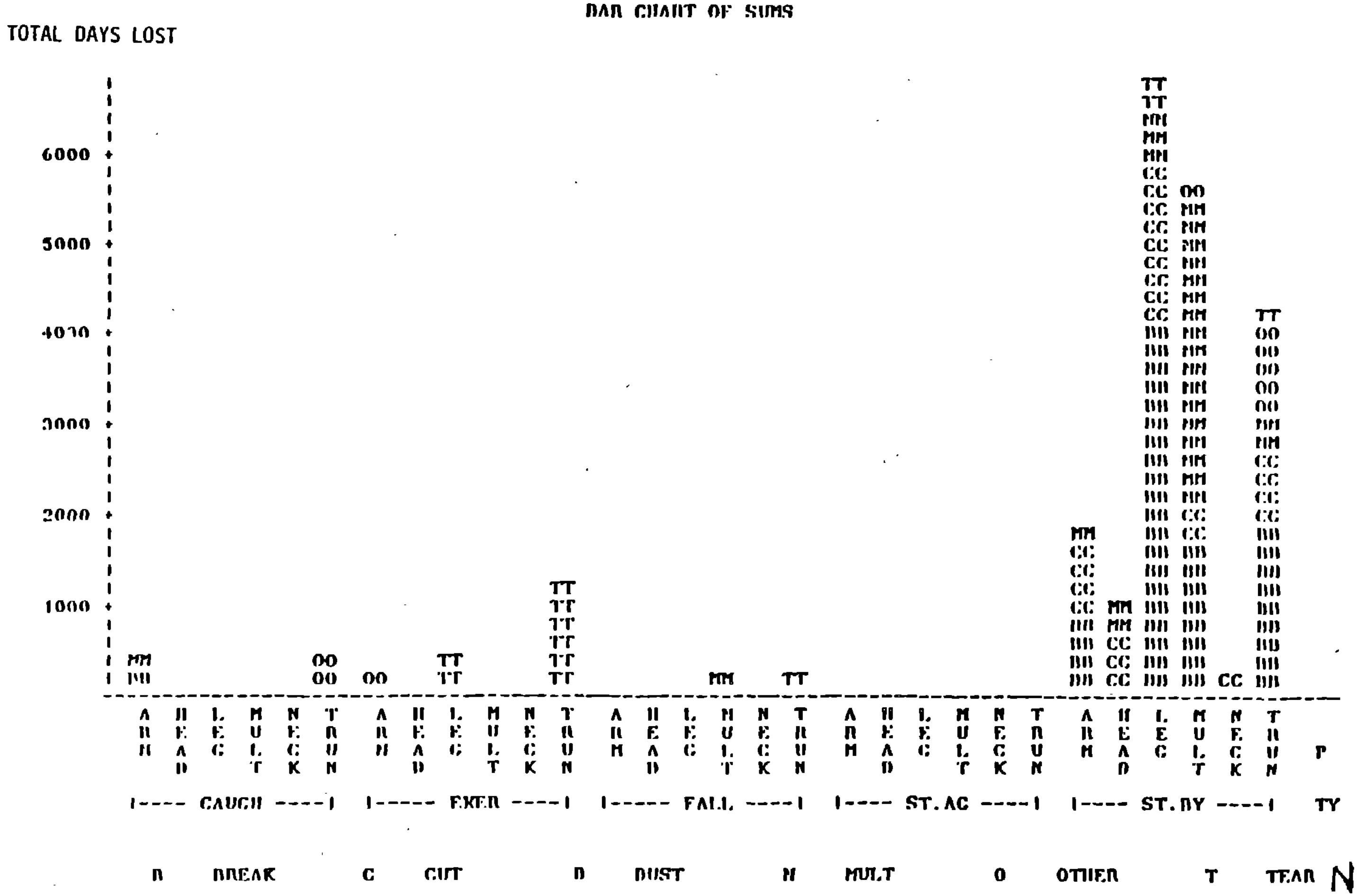
KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-10: Components of coal scaling bar accidents as a function of frequency.

COAL: SCALING BAR ACCIDENTS FOR ALL YEARS

BAR CHART OF SUMS



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-11: Components of coal scaling bar accidents as a function of days lost.

FIGURE 2-12: Tree diagram of scaling bar accidents in coal mines from 1978 to 1983 (N = 760).

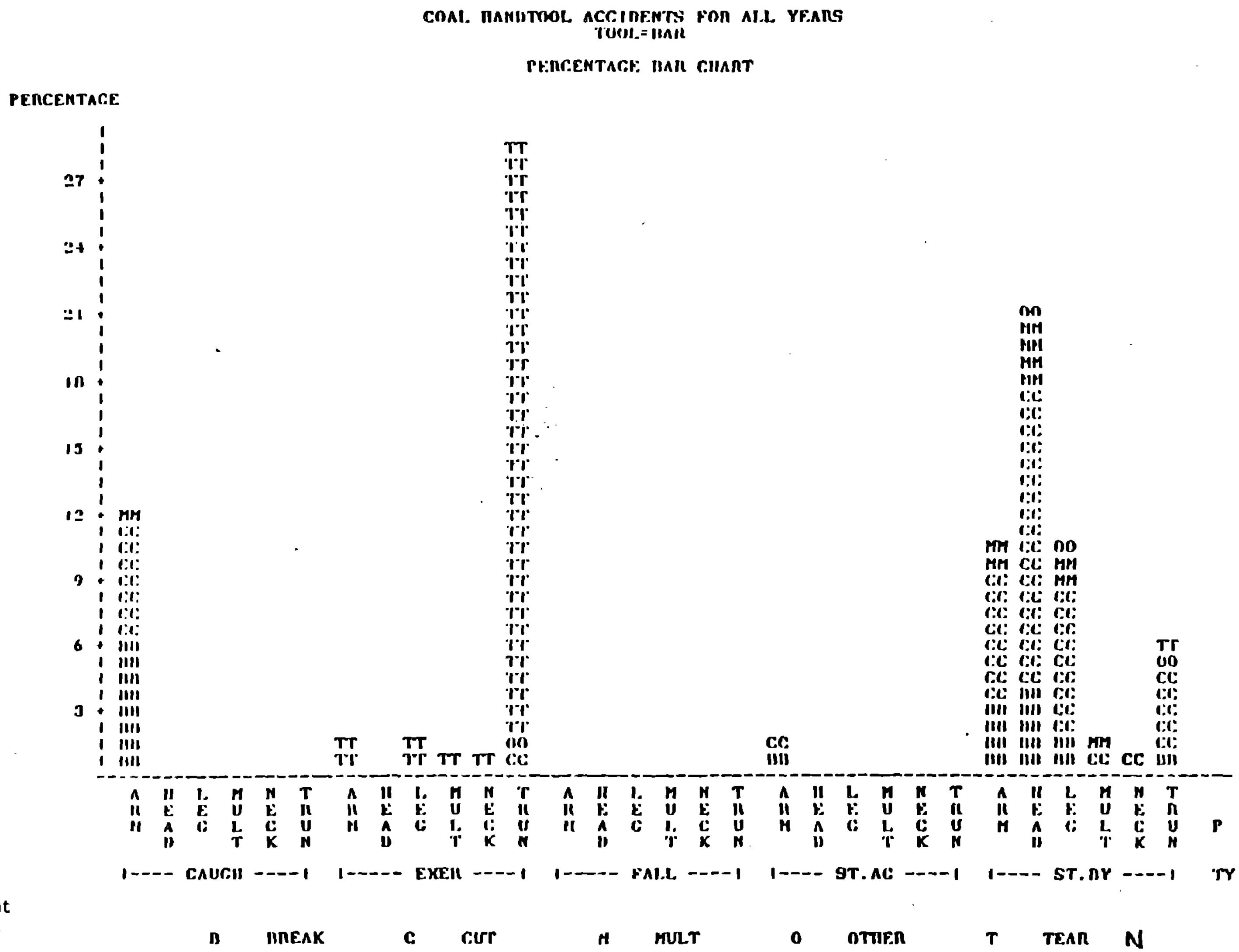
```
CAUGHT  N= 24  (0.032)
TDL=  982  MEAN= 37.50
                 ARM     N= 20  (  0.033)
                 TDL=  498  MEAN= 24.90
                                   BREAK   N= 10  (0.500)  PR=0.0132    DAYS LOST=  26.40
                                   CUT     N=  7  (0.350)  PR=0.0092    DAYS LOST=   9.43
                                   MULT    N=  2  (0.100)  PR=0.0026    DAYS LOST=  82.00
                                   OTHER   N=  1  (0.050)  PR=0.0013    DAYS LOST=   4.00
                 LEG     N=  2  (0.003)
                 TDL=   51  MEAN= 25.50
                                   MULT    N=  1  (0.500)  PR=0.0013    DAYS LOST=  34.00
                                   OTHER   N=  1  (0.500)  PR=0.0013    DAYS LOST=  17.00
                 TRUNK N=  2  (0.003)
                 TDL=  353  MEAN=176.50
                                   CUT     N=  1  (0.500)  PR=0.0013    DAYS LOST=  28.00
                                   OTHER   N=  1  (0.500)  PR=0.0013    DAYS LOST= 325.00

EXERTION  N= 89  (0.117)
TDL= 1950  MEAN= 21.91
                 ARM     N=  5  (  0.056)
                 TDL=  243  MEAN= 48.60
                                   CUT     N=  1  (0.200)  PR=0.0013    DAYS LOST=   0.00
                                   OTHER   N=  1  (0.200)  PR=0.0013    DAYS LOST= 235.00
                                   TEAR    N=  3  (0.600)  PR=0.0039    DAYS LOST=   2.67
                 LEG     N=  3  (0.034)
                 TDL=  304  MEAN=120.00
                                   OTHER   N=  1  (0.333)  PR=0.0013    DAYS LOST=  31.00
                                   TEAR    N=  2  (0.667)  PR=0.0026    DAYS LOST= 176.50
                 MULT    N=  2  (0.022)
                 TDL=    3  MEAN=  1.50
                                   TEAR    N=  2  (1.000)  PR=0.0026    DAYS LOST=   1.50
                 NECK    N=  4  (0.045)
                 TDL=   45  MEAN= 11.25
                                   TEAR    N=  4  (1.000)  PR=0.0053    DAYS LOST=  11.25
                 TRUNK N= 75  (0.843)
                 TDL= 1276  MEAN= 17.00
                                   BREAK   N=  1  (0.013)  PR=0.0013    DAYS LOST=   6.00
                                   CUT     N=  3  (0.040)  PR=0.0039    DAYS LOST=   0.67
                                   MULT    N=  1  (0.013)  PR=0.0013    DAYS LOST=  15.00
                                   OTHER   N=  3  (0.040)  PR=0.0039    DAYS LOST=  20.00
                                   TEAR    N= 67  (0.893)  PR=0.0002    DAYS LOST=  17.79

FALL  N= 27  (0.036)
TDL=  642  MEAN= 23.78
                 ARM     N=  1  (  0.037)
                 TDL=    1  MEAN=  1.00
                                   BREAK   N=  1  (1.000)  PR=0.0013    DAYS LOST=   1.00
                 HEAD    N=  4  (0.148)
                 TDL=   25  MEAN=  6.26
                                   CUT     N=  4  (1.000)  PR=0.0053    DAYS LOST=   6.25
                 LEG     N=  4  (0.140)
                 TDL=    9  MEAN=  2.26
                                   TEAR    N=  4  (1.000)  PR=0.0053    DAYS LOST=   2.25
                 MULT    N=  6  (0.222)
                 TDL=  207  MEAN= 34.60
                                   CUT     N=  1  (0.167)  PR=0.0013    DAYS LOST=  10.00
                                   MULT    N=  4  (0.667)  PR=0.0053    DAYS LOST=  47.75
                                   TEAR    N=  1  (0.167)  PR=0.0013    DAYS LOST=   6.00
                 NECK    N=  1  (0.037)
                 TDL=   22  MEAN= 22.00
                                   TEAR    N=  1  (1.000)  PR=0.0013    DAYS LOST=  22.00
                 TRUNK N= 11  (0.407)
                 TDL=  370  MEAN= 34.36
                                   BREAK   N=  4  (0.364)  PR=0.0053    DAYS LOST=  23.50
```

```
                                             CUT    N=  1  (0.091)  PR=0.0013    DAYS LOST=  81.00
                                             MULT   N=  1  (0.091)  PR=0.0013    DAYS LOST=   2.00
                                             OTHER  N=  1  (0.091)  PR=0.0013    DAYS LOST=   4.00
                                             TEAR   N=  4  (0.364)  PR=0.0053    DAYS LOST=  49.25
STAG N= 19  (0.025)
TDL=  311  MEAN= 16.37
                            ARM    N= 11  (  0.579)
                            TDL=  115  MEAN= 10.45
                                             BREAK  N=  2  (0.182)  PR=0.0026    DAYS LOST=  25.00
                                             CUT    N=  9  (0.818)  PR=0.0110    DAYS LOST=   7.22
                            HEAD   N=  3  (0.158)
                            TDL=   17  MEAN=  6.67
                                             BREAK  N=  1  (0.333)  PR=0.0013    DAYS LOST=   6.00
                                             CUT    N=  2  (0.667)  PR=0.0026    DAYS LOST=   5.50
                            LEG    N=  2  (0.105)
                            TDL=   19  MEAN=  9.50
                                             CUT    N=  1  (0.500)  PR=0.0013    DAYS LOST=  19.00
                                             TEAR   N=  1  (0.500)  PR=0.0013    DAYS LOST=   0.00
                            MULT   N=  1  (0.053)
                            TDL=   53  MEAN= 53.00
                                             MULT   N=  1  (1.000)  PR=0.0013    DAYS LOST=  53.00
                            NECK  N=  1  (0.053)
                            TDL=   20  MEAN= 20.00
                                             CUT    N=  1  (1.000)  PR=0.0013    DAYS LOST=  20.00
                            TRUNK N=  1  (0.053)
                            TDL=   87  MEAN= 87.00
                                             CUT    N=  1  (1.000)  PR=0.0013    DAYS LOST=  87.00
STBY N=601  (0.791)
TDL=19796  MEAN= 32.94
                            ARM    N=115  (  0.191)
                            TDL= 1796  MEAN= 15.62
                                             BREAK  N= 23  (0.200)  PR=0.0303    DAYS LOST=  31.17
                                             CUT    N= 72  (0.626)  PR=0.0947    DAYS LOST=  10.38
                                             MULT   N= 14  (0.122)  PR=0.0184    DAYS LOST=  21.21
                                             OTHER  N=  3  (0.026)  PR=0.0039    DAYS LOST=   8.33
                                             TEAR   N=  3  (0.026)  PR=0.0039    DAYS LOST=   3.33
                            HEAD   N= 73  (0.121)
                            TDL= 1044  MEAN= 14.30
                                             BREAK  N=  8  (0.110)  PR=0.0105    DAYS LOST=   6.25
                                             CUT    N= 47  (0.644)  PR=0.0618    DAYS LOST=  10.91
                                             DUST   N=  7  (0.096)  PR=0.0092    DAYS LOST=   4.57
                                             MULT   N=  5  (0.060)  PR=0.0066    DAYS LOST=  84.20
                                             OTHER  N=  6  (0.082)  PR=0.0079    DAYS LOST=   4.67
                            LEG    N=239  (0.398)
                            TDL= 6763  MEAN= 28.30
                                             BREAK  N= 72  (0.301)  PR=0.0947    DAYS LOST=  55.35
                                             CUT    N=127  (0.531)  PR=0.1671    DAYS LOST=  14.00
                                             MULT   N= 19  (0.079)  PR=0.0250    DAYS LOST=  27.60
                                             OTHER  N=  6  (0.025)  PR=0.0079    DAYS LOST=  14.50
                                             TEAR   N= 16  (0.063)  PR=0.0197    DAYS LOST=  25.00
                            MULT   N= 67  (0.111)
                            TDL= 5671  MEAN= 84.64
                                             BREAK  N=  7  (0.104)  PR=0.0092    DAYS LOST= 230.00
                                             CUT    N= 25  (0.373)  PR=0.0329    DAYS LOST=  10.24
                                             MULT   N= 33  (0.493)  PR=0.0434    DAYS LOST= 105.82
                                             OTHER  N=  2  (0.030)  PR=0.0026    DAYS LOST=  56.50
                            NECK  N= 13  (0.022)
                            TDL=  224  MEAN= 17.23
                                             BREAK  N=  1  (0.077)  PR=0.0013    DAYS LOST=   2.00
                                             CUT    N=  7  (0.538)  PR=0.0092    DAYS LOST=  22.00
                                             OTHER  N=  1  (0.077)  PR=0.0013    DAYS LOST=  32.00
                                             TEAR   N=  4  (0.308)  PR=0.0053    DAYS LOST=   9.00
                            TRUNK N= 94  (0.156)
                            TDL= 4298  MEAN= 45.72
                                             BREAK  N= 23  (0.245)  PR=0.0303    DAYS LOST=  80.39
                                             CUT    N= 40  (0.511)  PR=0.0612    DAYS LOST=  16.21
```

```
MULT   N= 6  (0.064)  PR=0.0079    DAYS LOST=  75.67
OTHER  N= 11 (0.117)  PR=0.0145    DAYS LOST=  93.36
TEAR   N= 6  (0.064)  PR=0.0079    DAYS LOST=  31.67

TOTAL  DAYS  LOST  =  23601

AVERAGE DAYS LOST  =  31.054
```

KEY

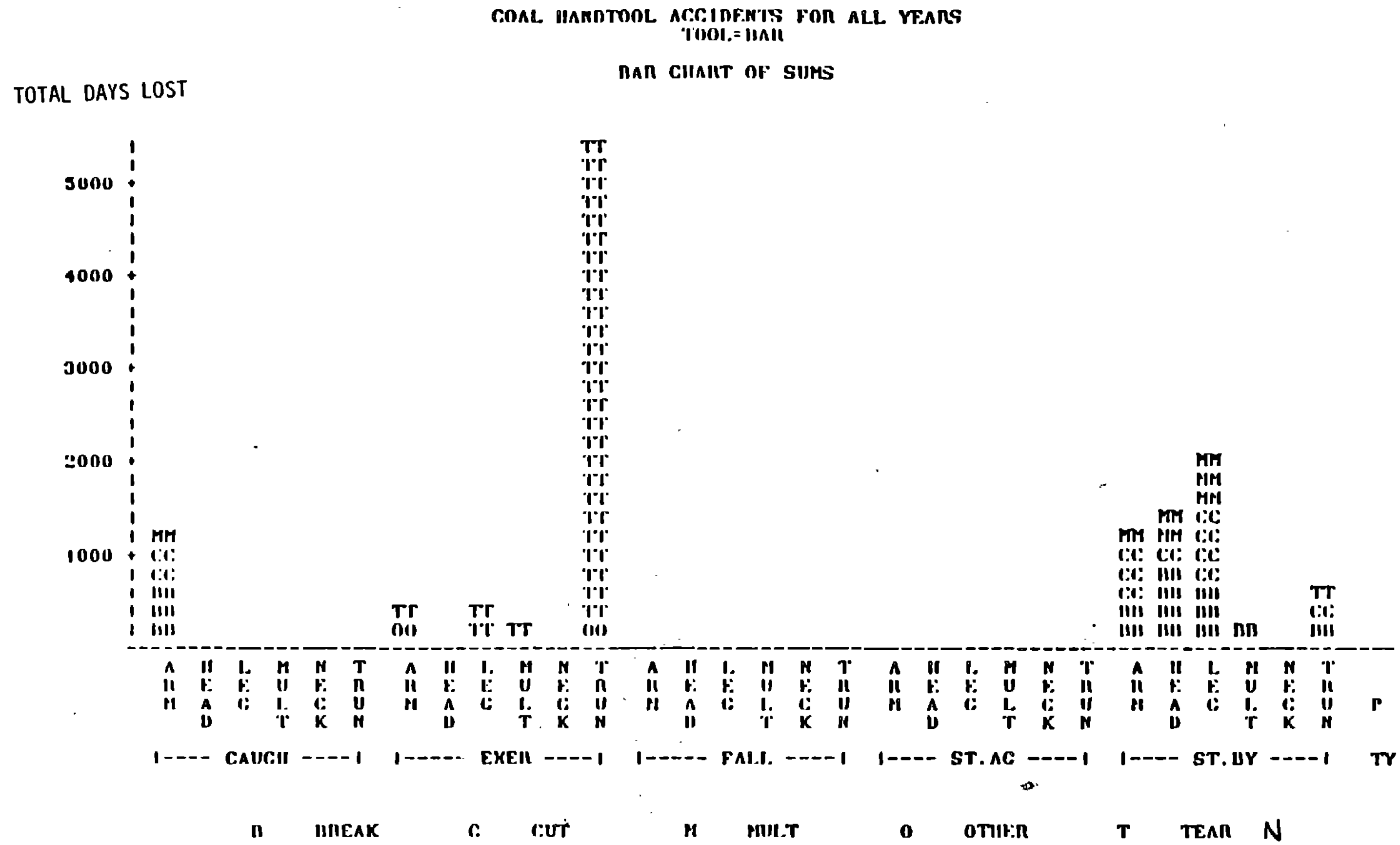
N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-13: Components of coal pry bar accidents as a function of frequency.



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-14: Components of coal pry bar accidents as a function of days lost.

FIGURE 2-15: Tree diagram of pry bar accidents in coal mines from 1978 to 1983 (N = 677).

```
CAUGHT  N=  84  ( 0.124)
TDL= 1334  MEAN=15.80
                 ARM    N=  81  ( 0.964)
                 TDL= 1208  MEAN=15.00
                                      BREAK   N= 39   (0.481)   PR= 0.0575    DAYS LOST=  16.23
                                      CUT     N= 34   (0.420)   PR= 0.0501    DAYS LOST=  12.62
                                      MULT    N=  6   (0.074)   PR= 0.0088    DAYS LOST=  36.33
                                      OTHER   N=  1   (0.012)   PR= 0.0015    DAYS LOST=   0.00
                                      TEAR    N=  1   (0.012)   PR= 0.0015    DAYS LOST=   0.00
                 HEAD   N=   1  ( 0.012)
                 TDL=    0  MEAN= 0.00
                                      CUT     N=  1   (1.000)   PR= 0.0016    DAYS LOST=   0.00
                 LEG    N=   1  ( 0.012)
                 TDL=   34  MEAN=34.00
                                      MULT    N=  1   (1.000)   PR= 0.0016    DAYS LOST=  34.00
                 TRUNK N=    1  ( 0.012)
                 TDL=   20  MEAN=20.00
                                      OTHER   N=  1   (1.000)   PR= 0.0015    DAYS LOST=  20.00

EXERTION  N= 227  ( 0.335)
TDL= 6648  MEAN=29.29
                 ARM    N=  18  ( 0.044)
                 TDL=  519  MEAN=51.90
                                      OTHER   N=  1   (0.100)   PR= 0.0015    DAYS LOST= 235.00
                                      TEAR    N=  9   (0.900)   PR= 0.0133    DAYS LOST=  31.56
                 LEG    N=  11  ( 0.048)
                 TDL=  503  MEAN=45.73
                                      BREAK   N=  1   (0.091)   PR= 0.0015    DAYS LOST=  29.00
                                      CUT     N=  1   (0.091)   PR= 0.0015    DAYS LOST=  36.00
                                      OTHER   N=  1   (0.091)   PR= 0.0015    DAYS LOST=  31.00
                                      TEAR    N=  8   (0.727)   PR= 0.0118    DAYS LOST=  50.88
                 MULT   N=   6  ( 0.026)
                 TDL=  202  MEAN=33.67
                                      TEAR    N=  6   (1.000)   PR= 0.0008    DAYS LOST=  33.67
                 NECK  N=    4  ( 0.010)
                 TDL=   52  MEAN=13.00
                                      TEAR    N=  4   (1.000)   PR= 0.0059    DAYS LOST=  13.00
                 TRUNK N= 196  ( 0.863)
                 TDL= 5372  MEAN=27.41
                                      BREAK   N=  1   (0.005)   PR= 0.0015    DAYS LOST=   0.00
                                      CUT     N=  3   (0.015)   PR= 0.0044    DAYS LOST=   4.00
                                      MULT    N=  2   (0.010)   PR= 0.0029    DAYS LOST=   8.00
                                      OTHER   N=  7   (0.036)   PR= 0.0103    DAYS LOST=  25.14
                                      TEAR    N=183   (0.934)   PR= 0.2699    DAYS LOST=  20.24

FALL N=    4  ( 0.006)
TDL=   12  MEAN= 3.00
                 ARM    N=   1  ( 0.250)
                 TDL=    0  MEAN= 0.00
                                      BREAK   N=  1   (1.000)   PR= 0.0016    DAYS LOST=   0.00
                 HEAD   N=   1  ( 0.250)
                 TDL=    0  MEAN= 0.00
                                      CUT     N=  1   (1.000)   PR= 0.0016    DAYS LOST=   0.00
                 TRUNK N=    2  ( 0.500)
                 TDL=   12  MEAN= 6.00
                                      CUT     N=  1   (0.500)   PR= 0.0016    DAYS LOST=   3.00
                                      MULT    N=  1   (0.500)   PR= 0.0015    DAYS LOST=   9.00

STAG N=  15  ( 0.022)
TDL=  150  MEAN=10.00
                 ARM    N=  11  ( 0.733)
                 TDL=   92  MEAN= 8.36
                                      BREAK   N=  4   (0.364)   PR= 0.0059    DAYS LOST=   8.00
                                      CUT     N=  6   (0.545)   PR= 0.0008    DAYS LOST=   4.17
```

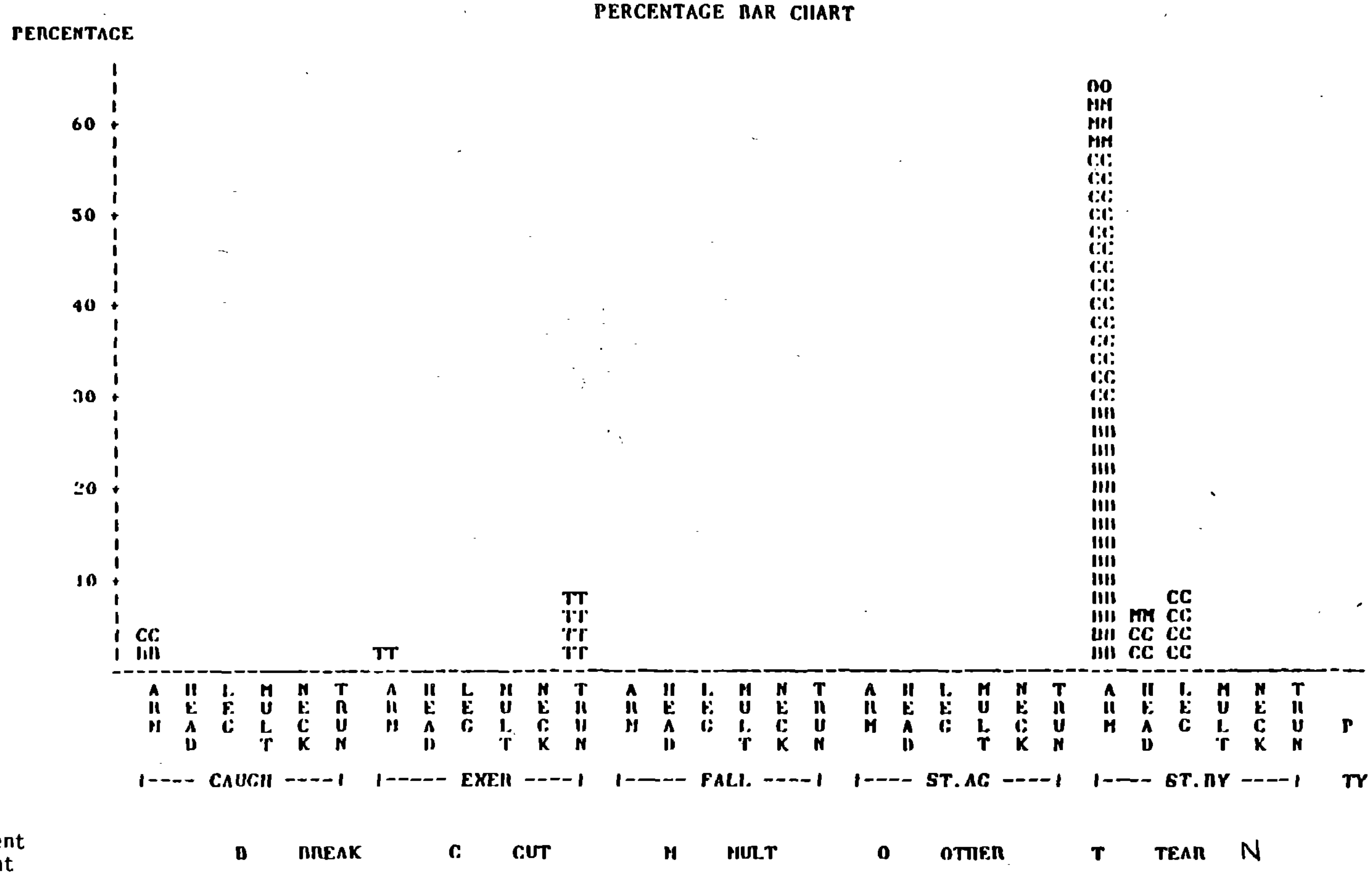
```
                                               TEAR   N-  1  (0.091)  PR- 0.0015    DAYS LOST-  35.00
                   HEAD   N-   3  ( 0.200)
                   TDL-   50  MEAN-19.33
                                               CUT    N-  2  (0.667)  PR- 0.0029    DAYS LOST-  29.00
                                               MULT   N-  1  (0.333)  PR- 0.0015    DAYS LOST-   0.00
                   TRUNK N-   1  ( 0.067)
                   TDL-    0  MEAN- 0.00
                                               CUT    N-  1  (1.000)  PR- 0.0015    DAYS LOST-   0.00
STBY N- 347  ( 0.512)
TDL- 5921  MEAN-17.06

                   ARM    N-  73  ( 0.210)
                   TDL- 1349  MEAN-10.40
                                               BREAK  N- 19  (0.260)  PR- 0.0280    DAYS LOST-  23.11
                                               CUT    N- 43  (0.509)  PR- 0.0634    DAYS LOST-  15.04
                                               MULT   N-  9  (0.123)  PR- 0.0133    DAYS LOST-  23.11
                                               OTHER  N-  1  (0.014)  PR- 0.0015    DAYS LOST-  21.00
                                               TEAR   N-  1  (0.014)  PR- 0.0015    DAYS LOST-   0.00
                   HEAD   N- 142  ( 0.409)
                   TDL- 1659  MEAN-11.60
                                               BREAK  N- 26  (0.183)  PR- 0.0383    DAYS LOST-  33.46
                                               CUT    N- 89  (0.627)  PR- 0.1313    DAYS LOST-   3.35
                                               MULT   N- 20  (0.141)  PR- 0.0295    DAYS LOST-  22.10
                                               OTHER  N-  6  (0.042)  PR- 0.0008    DAYS LOST-   5.83
                                               TEAR   N-  1  (0.007)  PR- 0.0015    DAYS LOST-  14.00
                   LEG    N-  74  ( 0.213)
                   TDL- 1909  MEAN-25.80
                                               BREAK  N- 12  (0.162)  PR- 0.0177    DAYS LOST-  43.83
                                               CUT    N- 47  (0.635)  PR- 0.0693    DAYS LOST-  17.17
                                               MULT   N-  8  (0.108)  PR- 0.0118    DAYS LOST-  69.00
                                               OTHER  N-  5  (0.060)  PR- 0.0074    DAYS LOST-   1.60
                                               TEAR   N-  2  (0.027)  PR- 0.0029    DAYS LOST-   8.00
                   MULT   N-   9  ( 0.026)
                   TDL-  269  MEAN-29.09
                                               BREAK  N-  1  (0.111)  PR- 0.0015    DAYS LOST- 130.00
                                               CUT    N-  4  (0.444)  PR- 0.0059    DAYS LOST-  15.50
                                               MULT   N-  3  (0.333)  PR- 0.0044    DAYS LOST-  22.00
                                               TEAR   N-  1  (0.111)  PR- 0.0015    DAYS LOST-  11.00
                   NECK   N-   5  ( 0.014)
                   TDL-   24  MEAN- 4.80
                                               CUT    N-  4  (0.800)  PR- 0.0059    DAYS LOST-   4.75
                                               MULT   N-  1  (0.200)  PR- 0.0015    DAYS LOST-   5.00
                   TRUNK N-  44  ( 0.127)
                   TDL-  711  MEAN-16.16
                                               BREAK  N-  7  (0.159)  PR- 0.0103    DAYS LOST-  31.43
                                               CUT    N- 26  (0.591)  PR- 0.0383    DAYS LOST-  11.15
                                               MULT   N-  1  (0.023)  PR- 0.0015    DAYS LOST-   0.00
                                               OTHER  N-  4  (0.091)  PR- 0.0059    DAYS LOST-   9.00
                                               TEAR   N-  6  (0.136)  PR- 0.0088    DAYS LOST-  27.50

        TOTAL  DAYS  LOST  -  14065

        AVERAGE DAYS LOST  -  20.745
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

COAL HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = HAMMER AND AXE

PERCENTAGE BAR CHART



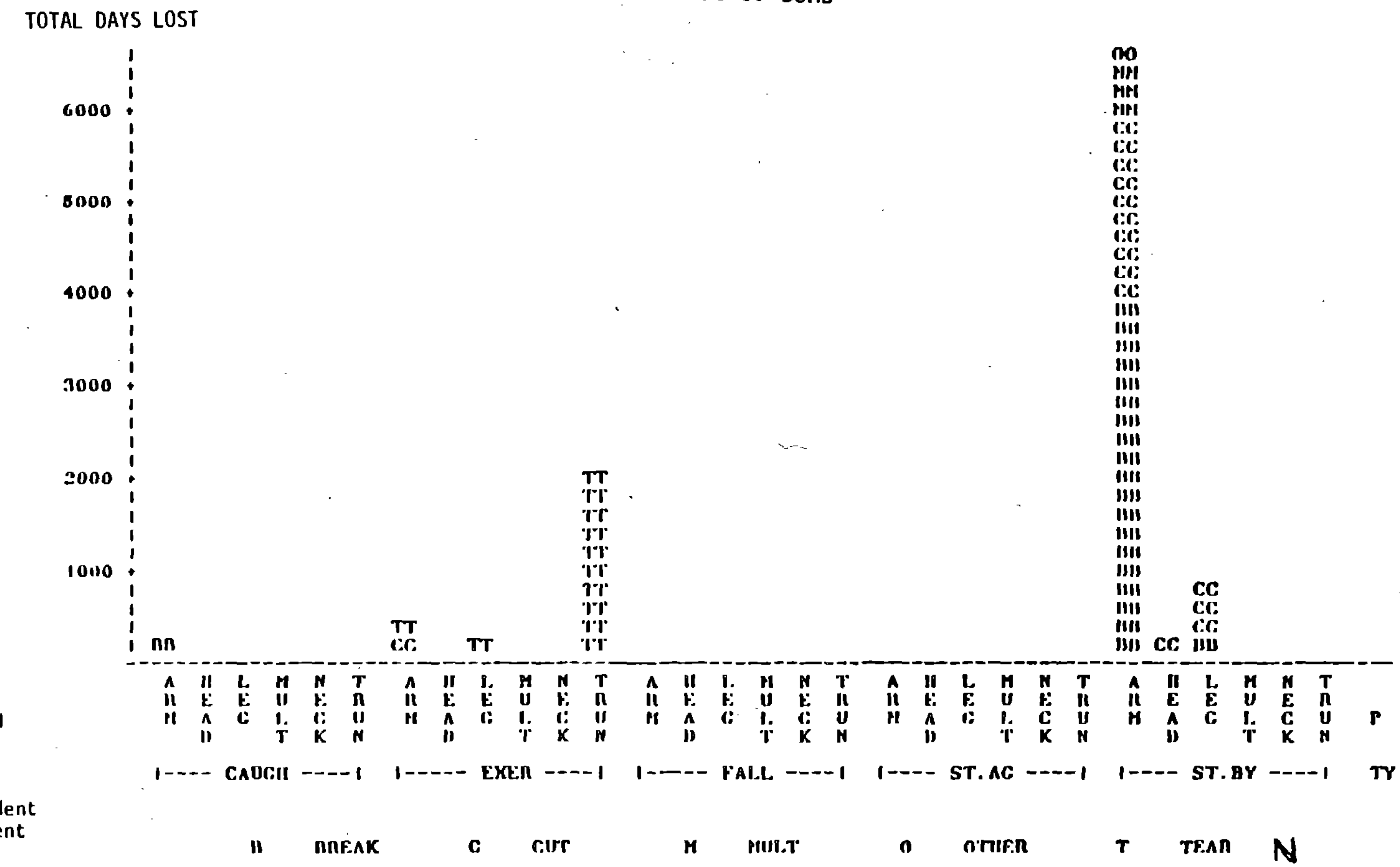
KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-16: Components of coal axe/hammer accidents as a function of frequency.

COAL HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = HAMMER AND AXE

BAR CHART OF SUMS



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-17: Components of coal axe/hammer accidents as a function of days lost.

FIGURE 2-18: Tree diagram of axe/hammer accidents in coal mines from 1978 to 1983 (N = 1104).

```
CAUGHT  N-  40  ( 0.036)
TOL=  306  MEAN- 7.65
                    ARM     N-  40  ( 1.000)
                    TOL-   306  MEAN- 7.65
                                        BREAK  N- 13  (0.325)  PR- 0.0118    DAYS LOST-   9.77
                                        CUT    N- 17  (0.425)  PR- 0.0154    DAYS LOST-   3.82
                                        MULT   N-  8  (0.200)  PR- 0.0072    DAYS LOST-  10.75
                                        OTHER  N-  2  (0.050)  PR- 0.0018    DAYS LOST-  14.00

EXERTION  N- 124  ( 0.112)
TOL- 2808  MEAN-22.65
                    ARM     N-  25  ( 0.202)
                    TOL-   437  MEAN-17.48
                                        BREAK  N-  1  (0.040)  PR- 0.0009    DAYS LOST-  63.00
                                        CUT    N-  2  (0.080)  PR- 0.0018    DAYS LOST-  65.50
                                        MULT   N-  1  (0.040)  PR- 0.0009    DAYS LOST-   2.00
                                        OTHER  N-  2  (0.080)  PR- 0.0018    DAYS LOST-   3.00
                                        TEAR   N- 19  (0.760)  PR- 0.0172    DAYS LOST-  12.37
                    LEG     N-   3  ( 0.024)
                    TOL-   167  MEAN-65.67
                                        CUT    N-  1  (0.333)  PR- 0.0009    DAYS LOST-   2.00
                                        TEAR   N-  2  (0.667)  PR- 0.0018    DAYS LOST-  82.50
                    MULT    N-   2  ( 0.016)
                    TOL-    12  MEAN- 6.00
                                        OTHER  N-  1  (0.500)  PR- 0.0009    DAYS LOST-  12.00
                                        TEAR   N-  1  (0.500)  PR- 0.0009    DAYS LOST-   0.00
                    NECK    N-   3  ( 0.024)
                    TOL-    36  MEAN-12.00
                                        TEAR   N-  3  (1.000)  PR- 0.0027    DAYS LOST-  12.00
                    TRUNK N-  91  ( 0.734)
                    TOL- 2156  MEAN-23.69
                                        CUT    N-  2  (0.022)  PR- 0.0018    DAYS LOST-   7.00
                                        OTHER  N-  4  (0.044)  PR- 0.0036    DAYS LOST-  22.75
                                        TEAR   N- 85  (0.934)  PR- 0.0769    DAYS LOST-  24.13

FALL N-    8  ( 0.007)
TOL-   88  MEAN-11.00
                    ARM     N-   1  ( 0.125)
                    TOL-     3  MEAN- 3.00
                                        BREAK  N-  1  (1.000)  PR- 0.0009    DAYS LOST-   3.00
                    LEG     N-   2  ( 0.250)
                    TOL-     0  MEAN- 0.00
                                        CUT    N-  2  (1.000)  PR- 0.0018    DAYS LOST-   0.00
                    TRUNK N-    5  ( 0.625)
                    TOL-    85  MEAN-17.00
                                        CUT    N-  2  (0.400)  PR- 0.0018    DAYS LOST-  20.50
                                        MULT   N-  1  (0.200)  PR- 0.0009    DAYS LOST-  39.00
                                        OTHER  N-  2  (0.400)  PR- 0.0018    DAYS LOST-   2.50

STAG N-    9  ( 0.008)
TOL=    46  MEAN- 5.11
                    ARM     N-   4  ( 0.444)
                    TOL-    32  MEAN- 8.00
                                        BREAK  N-  1  (0.250)  PR- 0.0009    DAYS LOST-   7.00
                                        CUT    N-  3  (0.750)  PR- 0.0027    DAYS LOST-   8.33
                    HEAD    N-   1  ( 0.111)
                    TOL-     1  MEAN- 1.00
                                        CUT    N-  1  (1.000)  PR- 0.0009    DAYS LOST-   1.00
                    LEG     N-   2  ( 0.222)
                    TOL-     5  MEAN- 2.50
                                        CUT    N-  2  (1.000)  PR- 0.0018    DAYS LOST-   2.50
                    TRUNK N-    2  ( 0.222)
                    TOL-     8  MEAN- 4.00
                                        CUT    N-  2  (1.000)  PR- 0.0018    DAYS LOST-   4.00

STBY N- 923  ( 0.835)
```

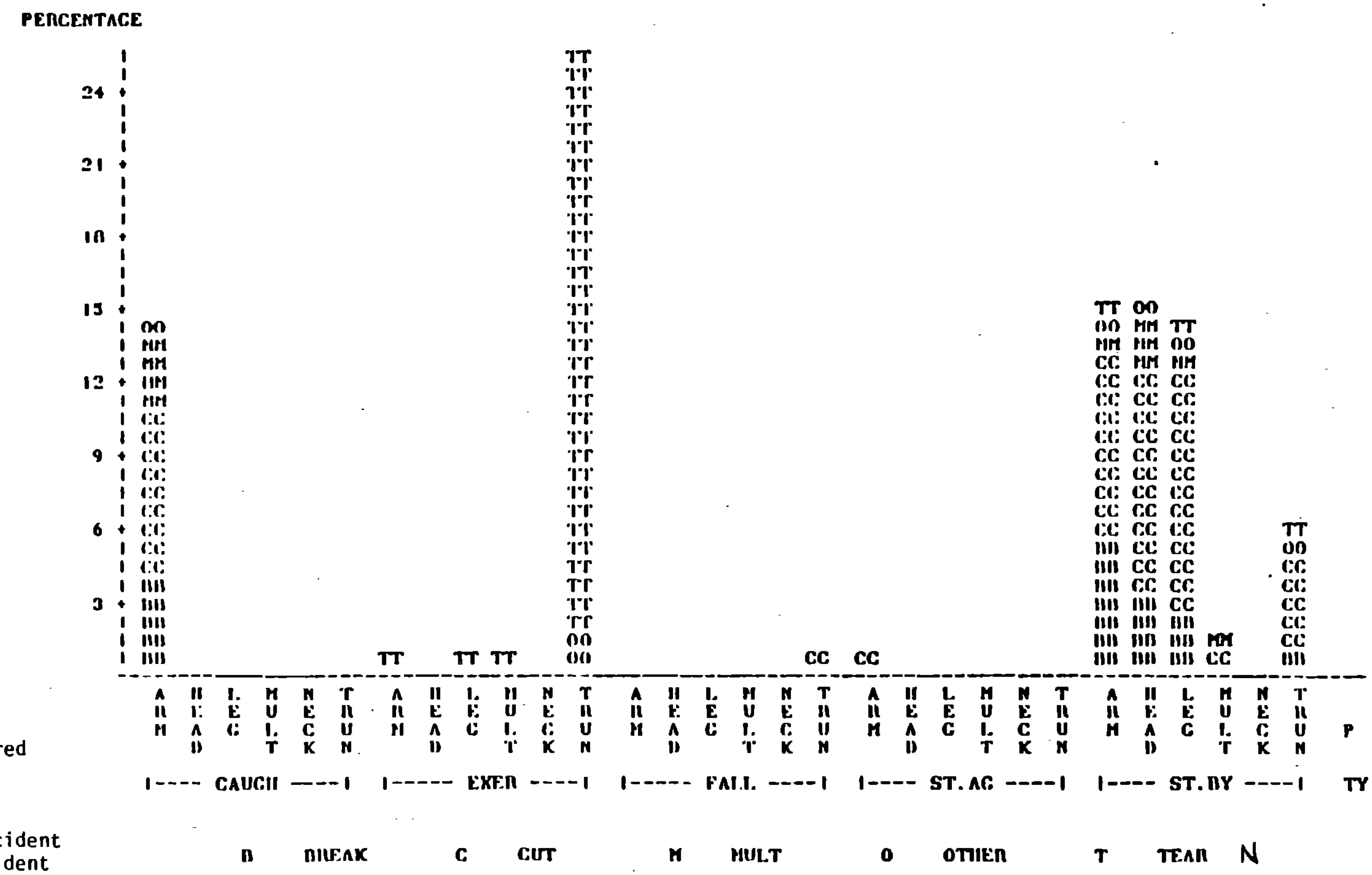
```
TDL= 7057  MEAN= 8.51
                    ARM     N= 721  ( 0.781)
                    TDL= 6676  MEAN= 9.26
                                        BREAK   N=304   (0.422)   PR= 0.2751     DAYS LOST=  12.42
                                        CUT     N=316   (0.438)   PR= 0.2860     DAYS LOST=   6.22
                                        MULT    N= 72   (0.100)   PR= 0.0652     DAYS LOST=   9.10
                                        OTHER   N= 23   (0.032)   PR= 0.0200     DAYS LOST=   7.22
                                        TEAR    N=  6   (0.008)   PR= 0.0054     DAYS LOST=  19.17
                    HEAD    N=  86  ( 0.093)
                    TDL=  257  MEAN= 2.99
                                        BREAK   N= 10   (0.116)   PR= 0.0090     DAYS LOST=   7.20
                                        CUT     N= 55   (0.640)   PR= 0.0498     DAYS LOST=   2.62
                                        MULT    N= 15   (0.174)   PR= 0.0136     DAYS LOST=   1.67
                                        OTHER   N=  6   (0.070)   PR= 0.0054     DAYS LOST=   2.67
                    LEG     N= 105  ( 0.114)
                    TDL=  878  MEAN= 8.36
                                        BREAK   N= 11   (0.105)   PR= 0.0100     DAYS LOST=  22.82
                                        CUT     N= 06   (0.019)   PR= 0.0770     DAYS LOST=   6.60
                                        MULT    N=  4   (0.038)   PR= 0.0036     DAYS LOST=  13.00
                                        OTHER   N=  4   (0.030)   PR= 0.0036     DAYS LOST=   1.75
                    MULT    N=   2  ( 0.002)
                    TDL=    0  MEAN= 0.00
                                        CUT     N=  1   (0.500)   PR= 0.0009     DAYS LOST=   0.00
                                        MULT    N=  1   (0.500)   PR= 0.0009     DAYS LOST=   0.00
                    NECK  N=     1  ( 0.001)
                    TDL=    0  MEAN= 0.00
                                        CUT     N=  1   (1.000)   PR= 0.0009     DAYS LOST=   0.00
                    TRUNK N=     8  ( 0.009)
                    TDL=   46  MEAN= 5.75
                                        BREAK   N=  1   (0.125)   PR= 0.0009     DAYS LOST=   0.00
                                        CUT     N=  7   (0.075)   PR= 0.0063     DAYS LOST=   6.57

          TOTAL  DAYS  LOST  =  11105

          AVERAGE DAYS LOST  =  10.050
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

COAL JACK ACCIDENTS FOR ALL YEARS

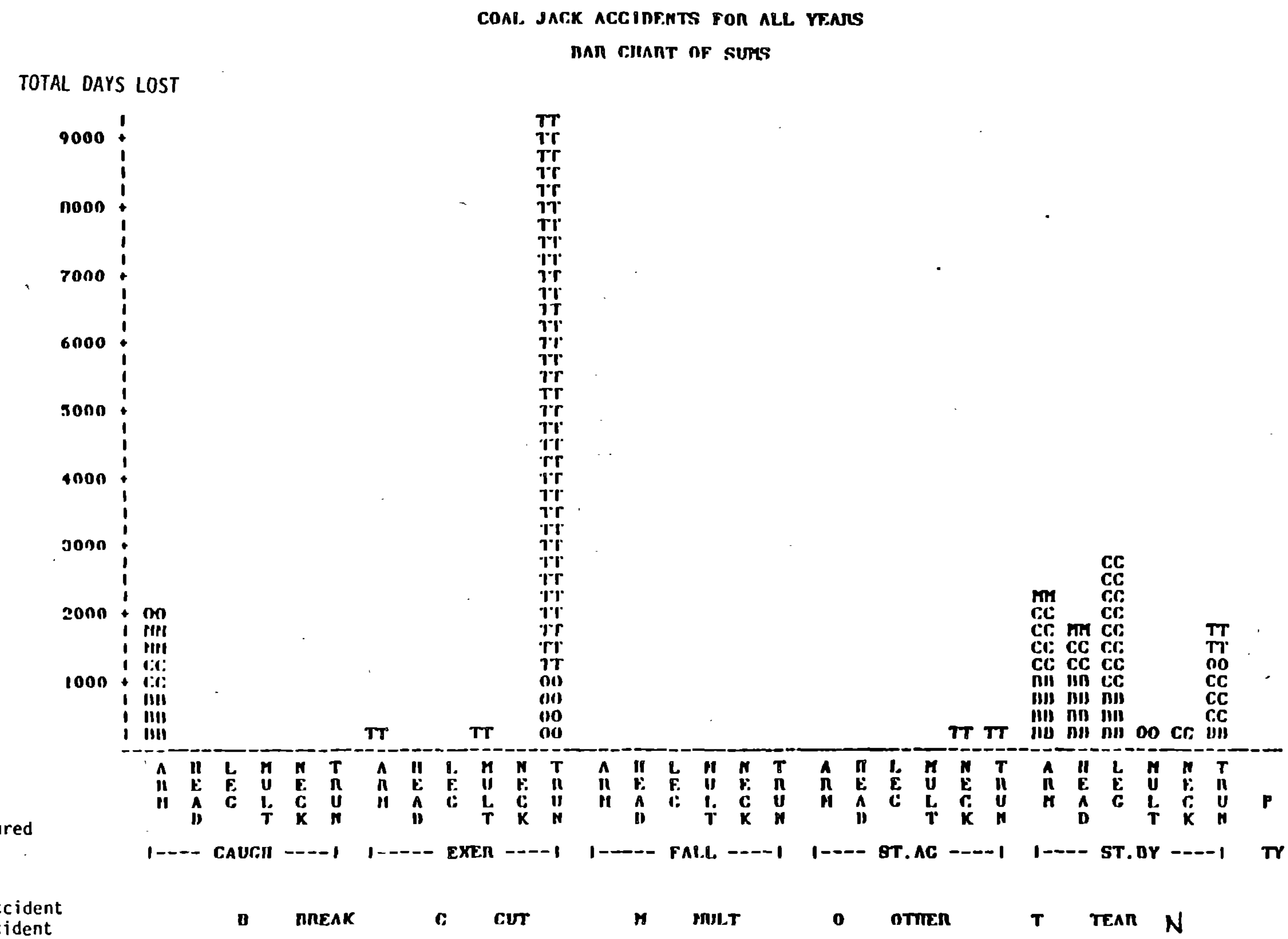
PERCENTAGE BAR CHART



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-19: Components of coal jack accidents as a function of frequency.



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-20: Components of coal jack accidents as a function of days lost.

FIGURE 2-21: Tree diagram of jack accidents in coal mines from 1978 to 1983 (N = 1139).

```
CAUGHT  N=171  (0.150)
TDL= 2027  MEAN= 11.05
                         ARM    N=163  ( 0.953)
                         TDL= 1911  MEAN= 11.72
                                         BREAK  N= 46  (0.282)  PR=0.0404   DAYS LOST=  17.11
                                         CUT    N= 79  (0.405)  PR=0.0694   DAYS LOST=   7.49
                                         MULT   N= 31  (0.190)  PR=0.0272   DAYS LOST=  12.13
                                         OTHER  N=  6  (0.037)  PR=0.0053   DAYS LOST=  22.50
                                         TEAR   N=  1  (0.006)  PR=0.0009   DAYS LOST=  21.00
                         LEG    N=  6  (0.035)
                         TDL=  104  MEAN= 17.33
                                         BREAK  N=  3  (0.500)  PR=0.0026   DAYS LOST=  29.00
                                         CUT    N=  3  (0.500)  PR=0.0026   DAYS LOST=   5.67
                         MULT   N=  1  (0.006)
                         TDL=    3  MEAN=  3.00
                                         CUT    N=  1  (1.000)  PR=0.0009   DAYS LOST=   3.00
                         NECK   N=  1  (0.006)
                         TDL=    9  MEAN=  9.00
                                         OTHER  N=  1  (1.000)  PR=0.0009   DAYS LOST=   9.00

EXERTION  N=324  (0.284)
TDL= 9870  MEAN= 30.49
                         ARM    N= 11  ( 0.034)
                         TDL=  275  MEAN= 25.00
                                         BREAK  N=  3  (0.273)  PR=0.0026   DAYS LOST=  27.67
                                         CUT    N=  1  (0.091)  PR=0.0009   DAYS LOST=  13.00
                                         OTHER  N=  1  (0.091)  PR=0.0009   DAYS LOST=  12.00
                                         TEAR   N=  6  (0.545)  PR=0.0053   DAYS LOST=  27.83
                         LEG    N= 10  (0.031)
                         TDL=  113  MEAN= 11.30
                                         TEAR   N= 10  (1.000)  PR=0.0088   DAYS LOST=  11.30
                         MULT   N=  6  (0.019)
                         TDL=  205  MEAN= 34.17
                                         TEAR   N=  6  (1.000)  PR=0.0053   DAYS LOST=  34.17
                         NECK   N=  3  (0.009)
                         TDL=   80  MEAN= 26.67
                                         TEAR   N=  3  (1.000)  PR=0.0026   DAYS LOST=  26.67
                         TRUNK  N=294  (0.907)
                         TDL= 9205  MEAN= 31.31
                                         BREAK  N=  1  (0.003)  PR=0.0009   DAYS LOST=  11.00
                                         OTHER  N= 16  (0.054)  PR=0.0140   DAYS LOST=  60.50
                                         TEAR   N=277  (0.942)  PR=0.2432   DAYS LOST=  29.81

FALL  N= 18  (0.016)
TDL=  320  MEAN= 17.78
                         ARM    N=  2  ( 0.111)
                         TDL=   66  MEAN= 33.00
                                         BREAK  N=  1  (0.500)  PR=0.0009   DAYS LOST=  65.00
                                         CUT    N=  1  (0.500)  PR=0.0009   DAYS LOST=   1.00
                         HEAD   N=  2  (0.111)
                         TDL=    5  MEAN=  2.50
                                         CUT    N=  2  (1.000)  PR=0.0018   DAYS LOST=   2.50
                         LEG    N=  2  (0.111)
                         TDL=    9  MEAN=  4.50
                                         BREAK  N=  1  (0.500)  PR=0.0009   DAYS LOST=   7.00
                                         TEAR   N=  1  (0.500)  PR=0.0009   DAYS LOST=   2.00
                         MULT   N=  1  (0.056)
                         TDL=   20  MEAN= 20.00
                                         TEAR   N=  1  (1.000)  PR=0.0009   DAYS LOST=  20.00
                         TRUNK  N= 11  (0.611)
                         TDL=  220  MEAN= 20.00
                                         CUT    N=  6  (0.545)  PR=0.0053   DAYS LOST=  12.67
                                         OTHER  N=  1  (0.091)  PR=0.0009   DAYS LOST=  52.00
                                         TEAR   N=  4  (0.364)  PR=0.0035   DAYS LOST=  23.00
```

```
STAG N= 32  (0.020)
TDL=  744  MEAN= 23.25
                    ARM     N= 14  (  0.438)
                    TDL=  100  MEAN=  7.71
                                             BREAK  N=  2  (0.143)  PR=0.0018   DAYS LOST=  29.50
                                             CUT    N=  8  (0.571)  PR=0.0070   DAYS LOST=   3.00
                                             MULT   N=  2  (0.143)  PR=0.0018   DAYS LOST=   4.00
                                             OTHER  N=  1  (0.071)  PR=0.0009   DAYS LOST=   0.00
                                             TEAR   N=  1  (0.071)  PR=0.0009   DAYS LOST=   9.00
                    HEAD    N=  2  (0.063)
                    TDL=  165  MEAN= 82.50
                                             CUT    N=  1  (0.500)  PR=0.0009   DAYS LOST=  76.00
                                             OTHER  N=  1  (0.500)  PR=0.0009   DAYS LOST=  89.00
                    LEG     N=  3  (0.094)
                    TDL=    4  MEAN=  1.33
                                             CUT    N=  3  (1.000)  PR=0.0026   DAYS LOST=   1.33
                    MULT    N=  1  (0.031)
                    TDL=   52  MEAN= 52.00
                                             TEAR   N=  1  (1.000)  PR=0.0009   DAYS LOST=  52.00
                    NECK   N=  5  (0.156)
                    TDL=  162  MEAN= 32.40
                                             CUT    N=  1  (0.200)  PR=0.0009   DAYS LOST=  20.00
                                             TEAR   N=  4  (0.800)  PR=0.0035   DAYS LOST=  35.50
                    TRUNK N=  7  (0.219)
                    TDL=  263  MEAN= 36.14
                                             CUT    N=  2  (0.286)  PR=0.0018   DAYS LOST=  19.00
                                             OTHER  N=  2  (0.206)  PR=0.0018   DAYS LOST=  20.50
                                             TEAR   N=  3  (0.429)  PR=0.0026   DAYS LOST=  52.67

STBY N=594  (0.522)
TDL= 9236  MEAN= 15.55
                    ARM     N=173  (  0.291)
                    TDL= 2248  MEAN= 12.99
                                             BREAK  N= 61  (0.363)  PR=0.0536   DAYS LOST=  16.05
                                             CUT    N= 88  (0.509)  PR=0.0773   DAYS LOST=  10.06
                                             MULT   N= 12  (0.069)  PR=0.0105   DAYS LOST=  15.42
                                             OTHER  N=  5  (0.029)  PR=0.0044   DAYS LOST=  10.80
                                             TEAR   N=  7  (0.040)  PR=0.0061   DAYS LOST=  10.57
                    HEAD    N=172  (0.290)
                    TDL= 1790  MEAN= 10.45
                                             BREAK  N= 33  (0.192)  PR=0.0290   DAYS LOST=  27.12
                                             CUT    N=104  (0.605)  PR=0.0913   DAYS LOST=   4.46
                                             MULT   N= 23  (0.134)  PR=0.0202   DAYS LOST=  15.70
                                             OTHER  N= 12  (0.070)  PR=0.0105   DAYS LOST=   6.50
                    LEG     N=151  (0.254)
                    TDL= 2932  MEAN= 19.42
                                             BREAK  N= 26  (0.172)  PR=0.0228   DAYS LOST=  31.54
                                             CUT    N=110  (0.720)  PR=0.0966   DAYS LOST=  17.95
                                             MULT   N=  5  (0.033)  PR=0.0044   DAYS LOST=   2.40
                                             OTHER  N=  5  (0.033)  PR=0.0044   DAYS LOST=  21.00
                                             TEAR   N=  5  (0.033)  PR=0.0044   DAYS LOST=   4.00
                    MULT    N= 16  (0.027)
                    TDL=  305  MEAN= 19.06
                                             CUT    N=  7  (0.438)  PR=0.0061   DAYS LOST=  10.00
                                             MULT   N=  5  (0.313)  PR=0.0044   DAYS LOST=   5.60
                                             OTHER  N=  2  (0.125)  PR=0.0010   DAYS LOST=  76.00
                                             TEAR   N=  2  (0.125)  PR=0.0010   DAYS LOST=  27.50
                    NECK   N=  7  (0.012)
                    TDL=  243  MEAN= 34.71
                                             CUT    N=  3  (0.429)  PR=0.0026   DAYS LOST=  61.67
                                             MULT   N=  1  (0.143)  PR=0.0009   DAYS LOST=   5.00
                                             TEAR   N=  3  (0.429)  PR=0.0026   DAYS LOST=  17.67
                    TRUNK N= 75  (0.126)
                    TDL= 1710  MEAN= 22.80
                                             BREAK  N=  9  (0.120)  PR=0.0079   DAYS LOST=  14.89
                                             CUT    N= 45  (0.600)  PR=0.0395   DAYS LOST=  17.91
                                             MULT   N=  4  (0.053)  PR=0.0035   DAYS LOST=   7.75
                                             OTHER  N=  9  (0.120)  PR=0.0079   DAYS LOST=  23.70
```

TEAR N= 8 (0.107) PR=0.0070 DAYS LOST= 65.63

TOTAL DAYS LOST = 22205

AVERAGE DAYS LOST = 19.495

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

COAL HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL=KNIFE

PERCENTAGE BAR CHART

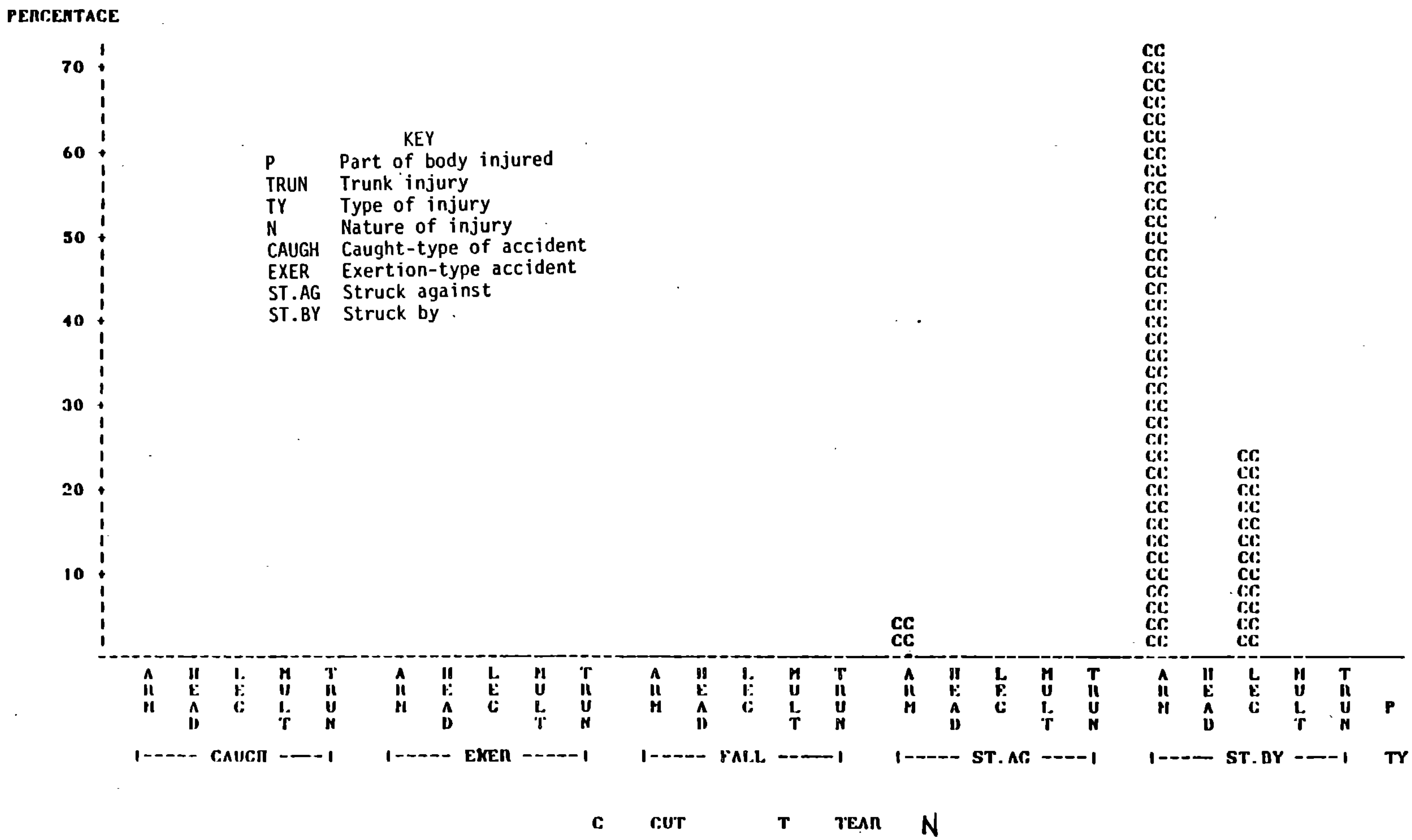


Figure 2-22: Components of coal knife injuries as a function of frequency.

COAL HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL=KNIFE

BAR CHART OF SUMS

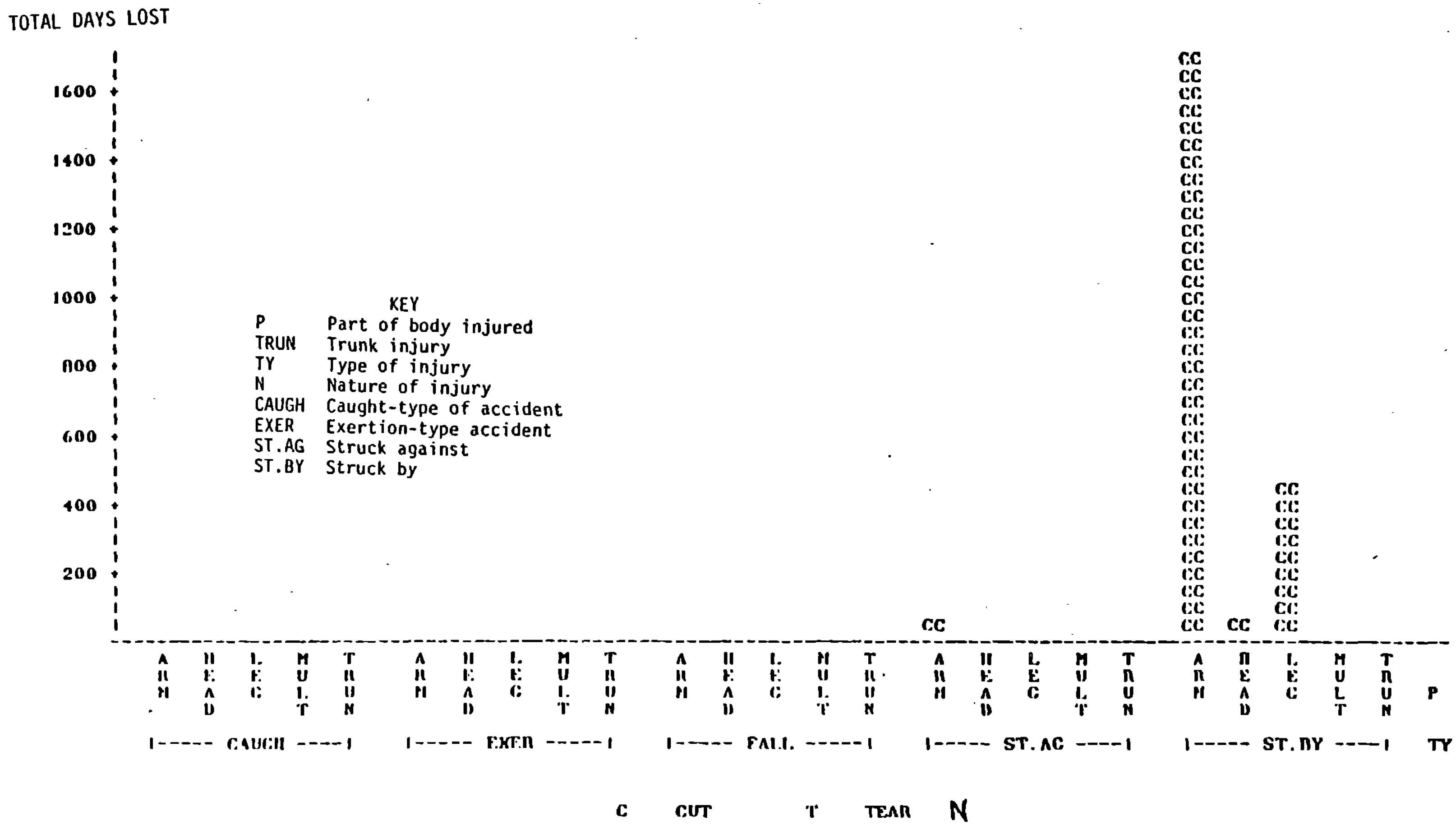


Figure 2-23: Components of coal knife injuries as a function of days lost.

FIGURE 2-24: Tree diagram of knife accidents in coal mines from 1978 to 1983 (N = 840).

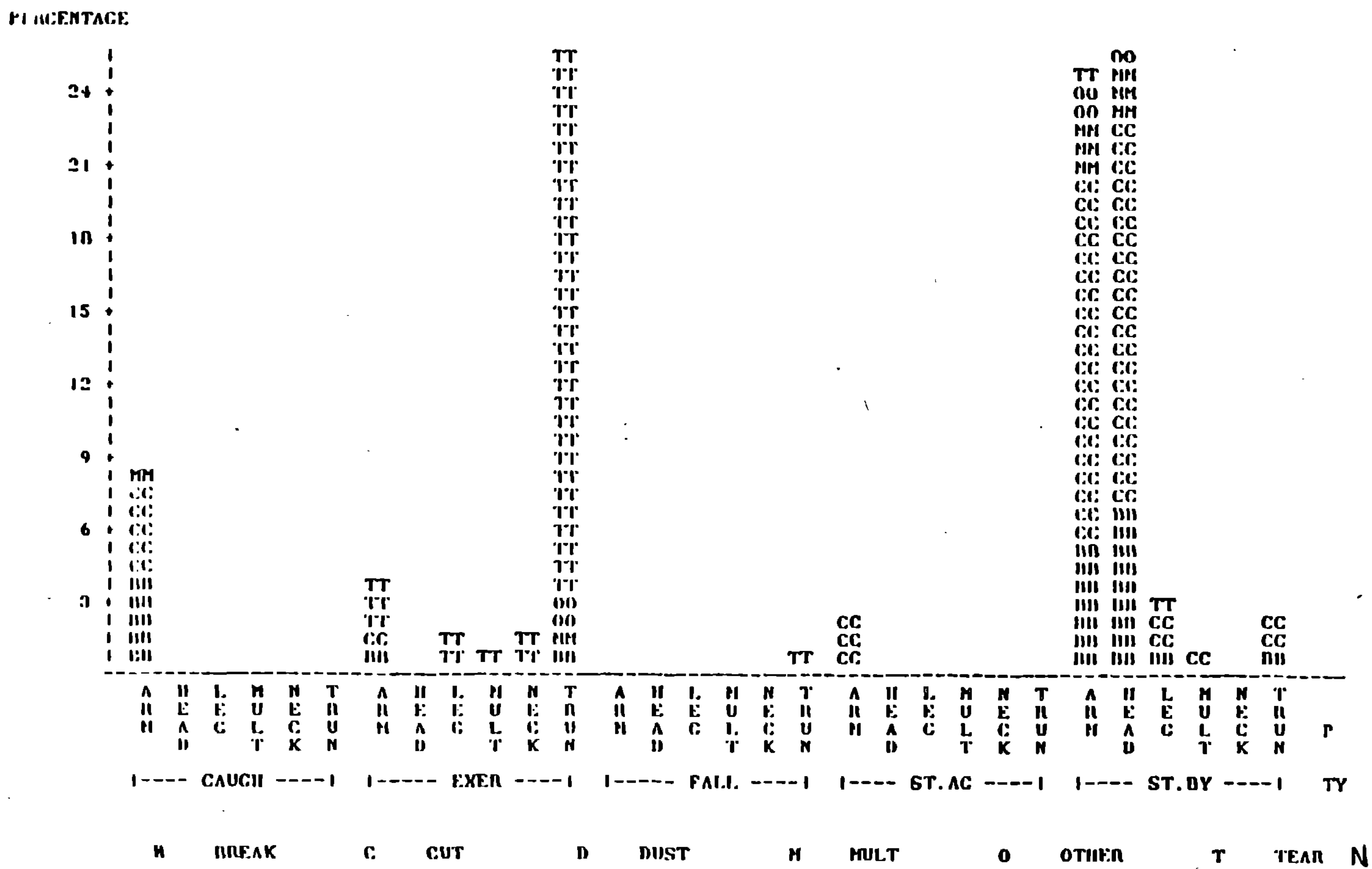
```
CAUGHT  N=   3  ( 0.004)
TDL=     1  MEAN= 0.33
                          ARM     N=    3  ( 1.000)
                          TDL=     1  MEAN= 0.33
                                              CUT     N=  3  (1.000)  PR= 0.0036    DAYS LOST=   0.33

EXERTION  N=    1  ( 0.001)
TDL=     3  MEAN= 3.00
                          TRUNK N=    1  ( 1.000)
                          TDL=     3  MEAN= 3.00
                                              TEAR    N=  1  (1.000)  PR= 0.0012    DAYS LOST=   3.00

FAIL N=   3  ( 0.004)
TDL=     1  MEAN= 0.33
                          ARM     N=    3  ( 1.000)
                          TDL=     1  MEAN= 0.33
                                              CUT     N=  3  (1.000)  PR= 0.0036    DAYS LOST=   0.33

STAG N=  32  ( 0.038)
TDL=    38  MEAN= 1.19
                          ARM     N=   28  ( 0.875)
                          TDL=    38  MEAN= 1.36
                                              CUT     N= 28  (1.000)  PR= 0.0333    DAYS LOST=   1.36
                          LEG     N=    4  ( 0.125)
                          TDL=     0  MEAN= 0.00
                                              CUT     N=  4  (1.000)  PR= 0.0048    DAYS LOST=   0.00

STBY N= 801  ( 0.952)
TDL= 2215  MEAN= 2.77
                          ARM     N= 601  ( 0.750)
                          TDL= 1723  MEAN= 2.87
                                              CUT     N=601  (1.000)  PR= 0.7146    DAYS LOST=   2.87
                          HEAD    N=    2  ( 0.002)
                          TDL=    35  MEAN=17.50
                                              CUT     N=  2  (1.000)  PR= 0.0024    DAYS LOST=  17.50
                          LEG     N= 197  ( 0.246)
                          TDL=   451  MEAN= 2.29
                                              CUT     N=197  (1.000)  PR= 0.2342    DAYS LOST=   2.29
                          MULT    N=    1  ( 0.001)
                          TDL=     6  MEAN= 6.00
                                              CUT     N=  1  (1.000)  PR= 0.0012    DAYS LOST=   6.00

          TOTAL  DAYS  LOST  =   2258

          AVERAGE DAYS LOST  =   2.685
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

COAL HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL=WRENCH

PERCENTAGE BAR CHART



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-25: Components of coal wrench injuries as a function of frequency.

COAL HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL=WRENCH

BAR CHART OF SUMS

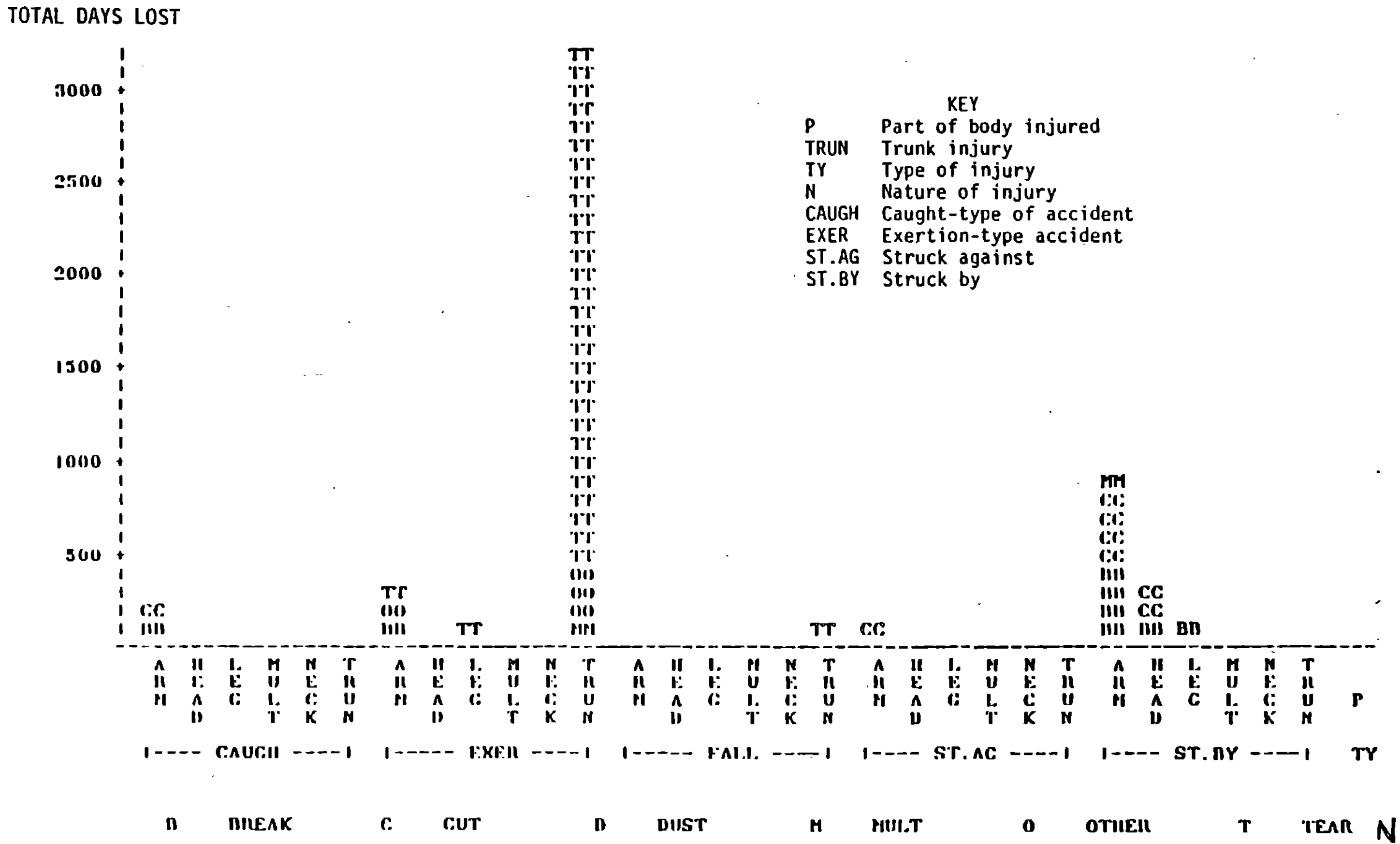


Figure 2-26: Components of coal wrench injuries as a function of days lost.

FIGURE 2-27: Tree diagram of wrench accidents in coal mines from 1978 to 1983 (N = 430).

```
CAUGHT  N=  37  ( 0.086)
TDL=  249  MEAN= 6.73
                ARM     N=  35  ( 0.946)
                TDL=  220  MEAN= 6.29
                                    BREAK   N= 15  (0.429)  PR= 0.0349   DAYS LOST=   9.60
                                    CUT     N= 16  (0.457)  PR= 0.0371   DAYS LOST=   4.19
                                    MULT    N=  3  (0.006)  PR= 0.0070   DAYS LOST=   2.67
                                    TEAR    N=  1  (0.029)  PR= 0.0023   DAYS LOST=   1.00
                LEG     N=   1  ( 0.027)
                TDL=   29  MEAN=29.00
                                    CUT     N=  1  (1.000)  PR= 0.0023   DAYS LOST=  29.00
                MULT    N=   1  ( 0.027)
                TDL=    0  MEAN= 0.00
                                    MULT    N=  1  (1.000)  PR= 0.0023   DAYS LOST=   0.00

EXERTION  N= 141  ( 0.327)
TDL= 3691  MEAN=26.10
                ARM     N=  16  ( 0.113)
                TDL=  290  MEAN=18.13
                                    BREAK   N=  3  (0.188)  PR= 0.0070   DAYS LOST=  40.67
                                    CUT     N=  3  (0.100)  PR= 0.0070   DAYS LOST=   0.33
                                    OTHER   N=  1  (0.063)  PR= 0.0023   DAYS LOST=  80.00
                                    TEAR    N=  9  (0.563)  PR= 0.0209   DAYS LOST=   9.67
                LEG     N=   0  ( 0.057)
                TDL=   67  MEAN= 0.30
                                    TEAR    N=  0  (1.000)  PR= 0.0106   DAYS LOST=   0.30
                MULT    N=   2  ( 0.014)
                TDL=   40  MEAN=20.00
                                    TEAR    N=  2  (1.000)  PR= 0.0046   DAYS LOST=  20.00
                NECK    N=   7  ( 0.050)
                TDL=   64  MEAN= 9.14
                                    OTHER   N=  1  (0.143)  PR= 0.0023   DAYS LOST=  23.00
                                    TEAR    N=  6  (0.057)  PR= 0.0139   DAYS LOST=   6.83
                TRUNK N= 108  ( 0.766)
                TDL= 3230  MEAN=29.91
                                    BREAK   N=  2  (0.019)  PR= 0.0046   DAYS LOST=  22.50
                                    MULT    N=  2  (0.019)  PR= 0.0046   DAYS LOST=  46.00
                                    OTHER   N=  5  (0.046)  PR= 0.0116   DAYS LOST=  55.20
                                    TEAR    N= 99  (0.917)  PR= 0.2297   DAYS LOST=  20.45

FALL  N=   5  ( 0.012)
TDL=  144  MEAN=28.80
                ARM     N=   2  ( 0.400)
                TDL=    0  MEAN= 0.00
                                    BREAK   N=  1  (0.500)  PR= 0.0023   DAYS LOST=   0.00
                                    TEAR    N=  1  (0.500)  PR= 0.0023   DAYS LOST=   0.00
                LEG     N=   1  ( 0.200)
                TDL=    1  MEAN= 1.00
                                    TEAR    N=  1  (1.000)  PR= 0.0023   DAYS LOST=   1.00
                TRUNK N=   2  ( 0.400)
                TDL=  143  MEAN=71.50
                                    TEAR    N=  2  (1.000)  PR= 0.0046   DAYS LOST=  71.50

STAG  N=  12  ( 0.020)
TDL=  105  MEAN= 8.75
                ARM     N=  10  ( 0.833)
                TDL=   91  MEAN= 9.10
                                    CUT     N=  9  (0.900)  PR= 0.0209   DAYS LOST=  10.11
                                    TEAR    N=  1  (0.100)  PR= 0.0023   DAYS LOST=   0.00
                HEAD    N=   1  ( 0.003)
                TDL=    2  MEAN= 2.00
                                    CUT     N=  1  (1.000)  PR= 0.0023   DAYS LOST=   2.00
                TRUNK N=   1  ( 0.003)
                TDL=   12  MEAN=12.00
                                    CUT     N=  1  (1.000)  PR= 0.0023   DAYS LOST=  12.00
```

```
STBY N= 235  ( 0.545)
TDL= 1499  MEAN= 6.30
                        ARM    N= 104  ( 0.443)
                        TDL=   900  MEAN= 8.65
                                              BREAK  N= 23  (0.221)  PR= 0.0534   DAYS LOST=  16.52
                                              CUT    N= 63  (0.606)  PR= 0.1462   DAYS LOST=   6.52
                                              MULT   N=  9  (0.087)  PR= 0.0209   DAYS LOST=   6.56
                                              OTHER  N=  5  (0.048)  PR= 0.0116   DAYS LOST=   8.20
                                              TEAR   N=  4  (0.038)  PR= 0.0093   DAYS LOST=   2.25
                        HEAD   N= 110  ( 0.460)
                        -TDL=  293  MEAN= 2.66
                                              BREAK  N= 28  (0.255)  PR= 0.0650   DAYS LOST=   2.07
                                              CUT    N= 69  (0.627)  PR= 0.1601   DAYS LOST=   2.04
                                              DUST   N=  1  (0.009)  PR= 0.0023   DAYS LOST=   3.00
                                              MULT   N= 10  (0.091)  PR= 0.0232   DAYS LOST=   3.00
                                              OTHER  N=  2  (0.018)  PR= 0.0046   DAYS LOST=   3.00
                        LEG    N=  10  ( 0.043)
                        TDL=   236  MEAN=23.60
                                              BREAK  N=  2  (0.200)  PR= 0.0046   DAYS LOST=  71.00
                                              CUT    N=  5  (0.500)  PR= 0.0116   DAYS LOST=   6.60
                                              OTHER  N=  1  (0.100)  PR= 0.0023   DAYS LOST=  20.00
                                              TEAR   N=  2  (0.200)  PR= 0.0046   DAYS LOST=  20.50
                        MULT   N=   2  ( 0.009)
                        TDL=     7  MEAN= 3.50
                                              CUT    N=  2  (1.000)  PR= 0.0046   DAYS LOST=   3.50
                        TRUNK N=    9  ( 0.038)
                        TDL=    63  MEAN= 7.00
                                              BREAK  N=  2  (0.222)  PR= 0.0046   DAYS LOST=   7.00
                                              CUT    N=  6  (0.667)  PR= 0.0139   DAYS LOST=   0.00
                                              MULT   N=  1  (0.111)  PR= 0.0023   DAYS LOST=   1.00

         TOTAL  DAYS  LOST  =   5600

         AVERAGE DAYS LOST  =  13.197
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

B. Evaluation of Hand Tools in Metal-Nonmetal Mining

Similar to coal mining, there are a variety of handtools that are used in underground metal-nonmetal mining, but only a few of them contribute to injuries that result in lost work days. The following seven tools will be discussed in terms of accident frequency and severity: (1) Pneumatic jackleg drill (JLD), (2) Roof and rib scaling bar, (3) Pry bar, (4) Axe and hammer, (5) Jack, (6) Knife, and (7) Wrench.

1. Jackleg Drill (JLD)

The components of JLD accidents in metal and nonmetal mining (MNM) are shown as a function of both frequency of occurrence and severity of injury in Figures 2-28 and 2-29, respectively. Figure 2-28 indicates that many of the injuries (62.4%) are due to struck-by accidents. Accidents involving a caught arm, and injuries to the trunk involving both exertion and falls are also common. Figure 2-29 shows that the severity cost of trunk injuries is relatively great when exertion and falling injuries are considered. Struck-by accidents also are associated with high lost-day costs.

Figure 2-30 shows the conditional relationship between the components of the jackleg drill injuries. This figure shows that exertion-trunk-tears, caught-arm-cuts, struck-by-leg-cuts, struck-by-head-cuts, and struck-by-arm-cuts are the accidents that are most likely to occur. Of these accidents, however, the average severity cost is greatest when the trunk is involved (about 10 days each for the 161 incidents).

2. Scaling Bar

The distribution of accident component frequencies are shown in Figure 2-31 for the scaling bar. This figure indicates that most of the injury frequency occurs due to struck-by accidents. These types of accidents most often result in cuts to the arms, legs, or head. An evaluation of lost-day costs reveals a slightly different picture. Figure 2-32 indicates that there is a heavy cost (in terms of lost days), compared to frequency of occurrence, associated with fall injuries affecting the leg and trunk. Struck-by accidents usually result in the greatest severity when the leg and when multiple injuries are involved.

Figure 2-33 shows the conditional relationship between accident components. This figure indicates that if a scaling bar injury occurs, there is an 18% chance of a struck-by accident resulting in a cut arm. There is also about a 12% risk of a struck-by accident resulting in a leg cut. These types of accidents, however, result in few mean lost days (3.1 to 5). The relative cost of trunk-exertion accidents is also apparent from this figure. The figure indicates that there were 52 tearing injuries resulting in a mean of over 19 lost days per incident. This type of injury could be expected about 5% of the time in scaling bar accidents.

3. Pry Bar

The distribution of frequency involving the components of pry bar injuries is shown for all years in Figure 2-34. This figure indicates that these injuries are usually due to caught (20.1%), exertion (26.1%) or struck-by accidents (50%). The parts of the body most often involved are either arm, trunk, or head. The severity cost of these injuries is shown in Figure 2-35. This figure indicates that the greatest problem with the pry bar results from a trunk exertion injury that results in soft-tissue tears.

The conditional relationship between the components of pry bar injuries is shown in Figure 2-36. This figure indicates that the greatest hazard lies in exertion injuries that tear the trunk tissue. Given that a bar accident occurs, there is a 21.6% chance that a trunk-tear injury will occur and an average of 15 days of lost-time could be expected. The figure shows that cuts to the arm, head, leg, and trunk, and breaks to the arm represent a substantial risk of injury; they are not, however, as severe as trunk-exertion injuries.

4. Axe and Hammer

As in the coal mining evaluation, the axe and hammer injuries were considered collectively due to the similarity in method of use and physical tool characteristics. Figure 2-37 shows the distribution of accident component frequency. As shown, almost all accidents were due to struck-by injuries (76.9%), with the majority involving the arm. The only other type of injury that occurred with any frequency (14%) were trunk-exertion injuries. The severity associated with these accident components is shown in Figure 2-38. Here again, struck-by accidents to the arm are responsible for the largest number of total days lost. However, as noted in the case of many other tools, trunk-exertion injuries also result in a disproportionately high severity relative to their frequency of occurrence.

The conditional relationship of the axe and hammer injuries is shown in Figure 2-39. This figure shows that exertion injuries to the trunk involving tears, and struck-by accidents involving break and cut injuries to the arm are the most serious problems in the use of the axe and hammer.

5. Jack

The frequency-related components of jack injuries is shown in Figure 2-40. This figure shows that struck-by injuries to the arm and head, as well as injuries that catch the arm in some way are the most common types. Most of these components also involve cuts. Figure 2-41 indicates that most of the severity associated with jack accidents involves cuts to the arm that result from struck-by and catching accidents. Additionally, trunk exertions that involve tears are significant in their total days lost.

The conditional relationship between injury components is shown in Figure 2-42 for the jack. This figure shows that the combined relative frequency and cost (days lost per occurrence) of a jack injury is greatest for struck-by-arm-cut, exertion-trunk-tear, and caught-arm-cut sequences.

6. Knife

The frequency of knife-related accidents, as related to injury components, is shown in Figure 2-43. Nearly all of these injuries (89%) involved cuts to the arm from being struck-by the tool. Figure 2-44 shows this type of accident was also responsible for approximately 85% of all lost days. Figure 2-45 shows the conditional relationship among the accident components. This figure also shows the limited nature of knife injuries. Only two of these branches (struck-by-arm-cut and struck-by-leg-cut) can be considered significant.

7. Wrench

The frequency distribution of wrench injury components is shown in Figure 2-46. This figure represents a total of 189 incidents. As with many of the other leverage-type tools (scaling bar, pry bar, and the jack), the wrench accidents primarily involve struck-by injuries to the arm and head, trunk-exertion injuries, and injuries involving caught arms. Figure 2-47 shows the days lost due to wrench injuries. This figure indicates that the trunk-exertion injuries involving soft-tissue tears result in the most lost days, followed by struck-by injuries to the arm and head. The caught injuries are not as costly in terms of severity as indicated by the frequency of injury.

Figure 2-48 shows the conditional relationship among the components of wrench injuries. This figure indicates that the greatest risk (19.5%) and greatest cost is associated with trunk-exertion injuries that involve tears to the soft tissue (an average of almost 20 lost days for the 37 incidents).

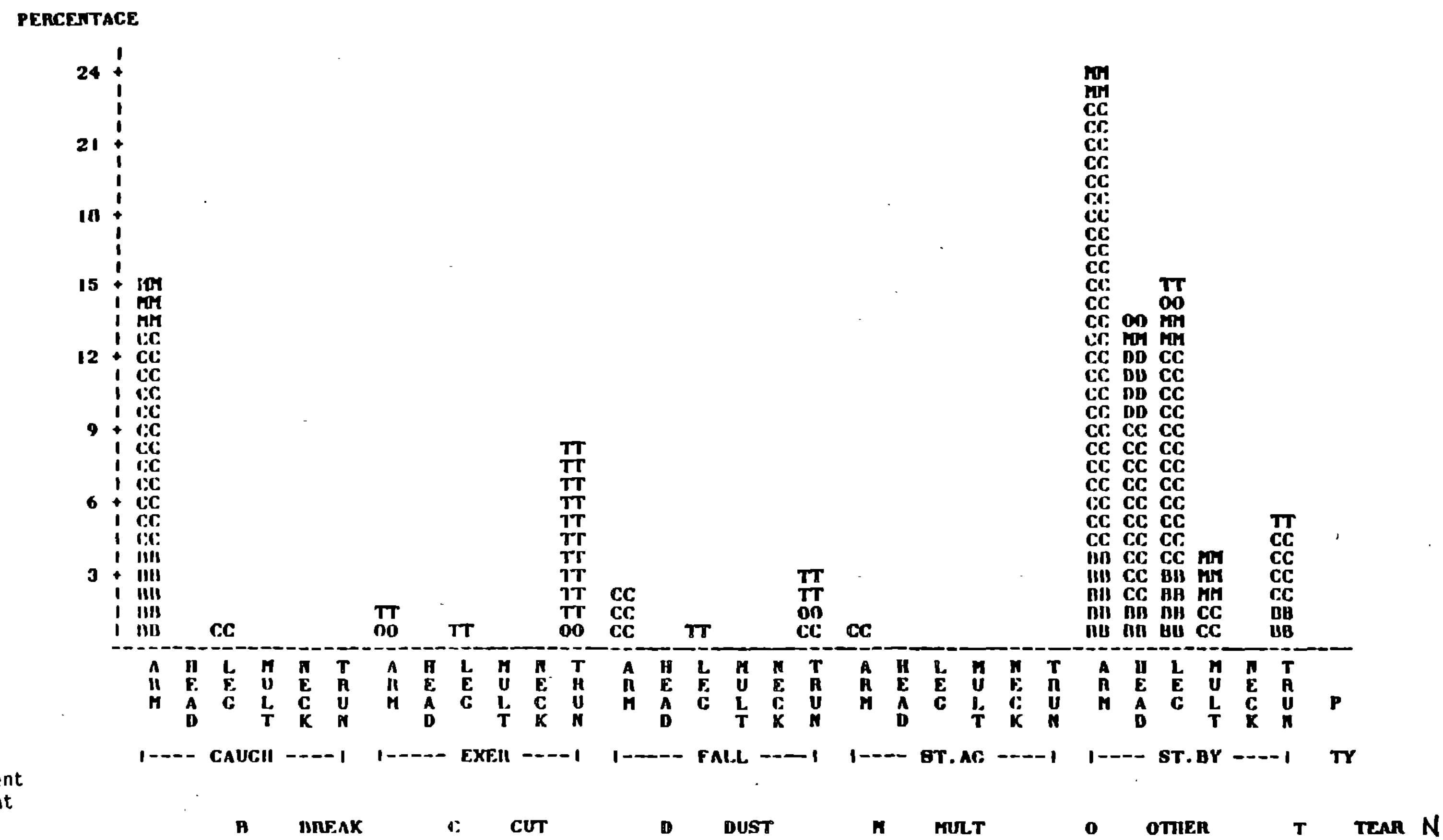
Struck-by accidents involving cuts to the arms can be expected to occur 20% of the time that a wrench is used; this injury sequence results in an average of approximately 3/4 of a lost work-day. Struck-by accidents that cause a break to the arm, however, will result in an average of more than 10 lost work-days; this accident sequence occurs only 3.6% of the time that a wrench is used. Struck-by accidents causing cuts to the head can be expected to occur 13.2% of the time, and will average 4.24 lost work-days per incident.

SUMMARY

These statistics are discussed in the next sction of this chapter. Specifically, tables 2-4, 2-6, and 2-8, and figure 2-50 present an overview of the frequency and severity of handtool-related lost-time accidents that occurred in underground metal-nonmetal mining during 1978 to 1983.

METAL: JACKLEG DRILL ACCIDENTS FOR ALL YEARS

PERCENTAGE BAR CHART



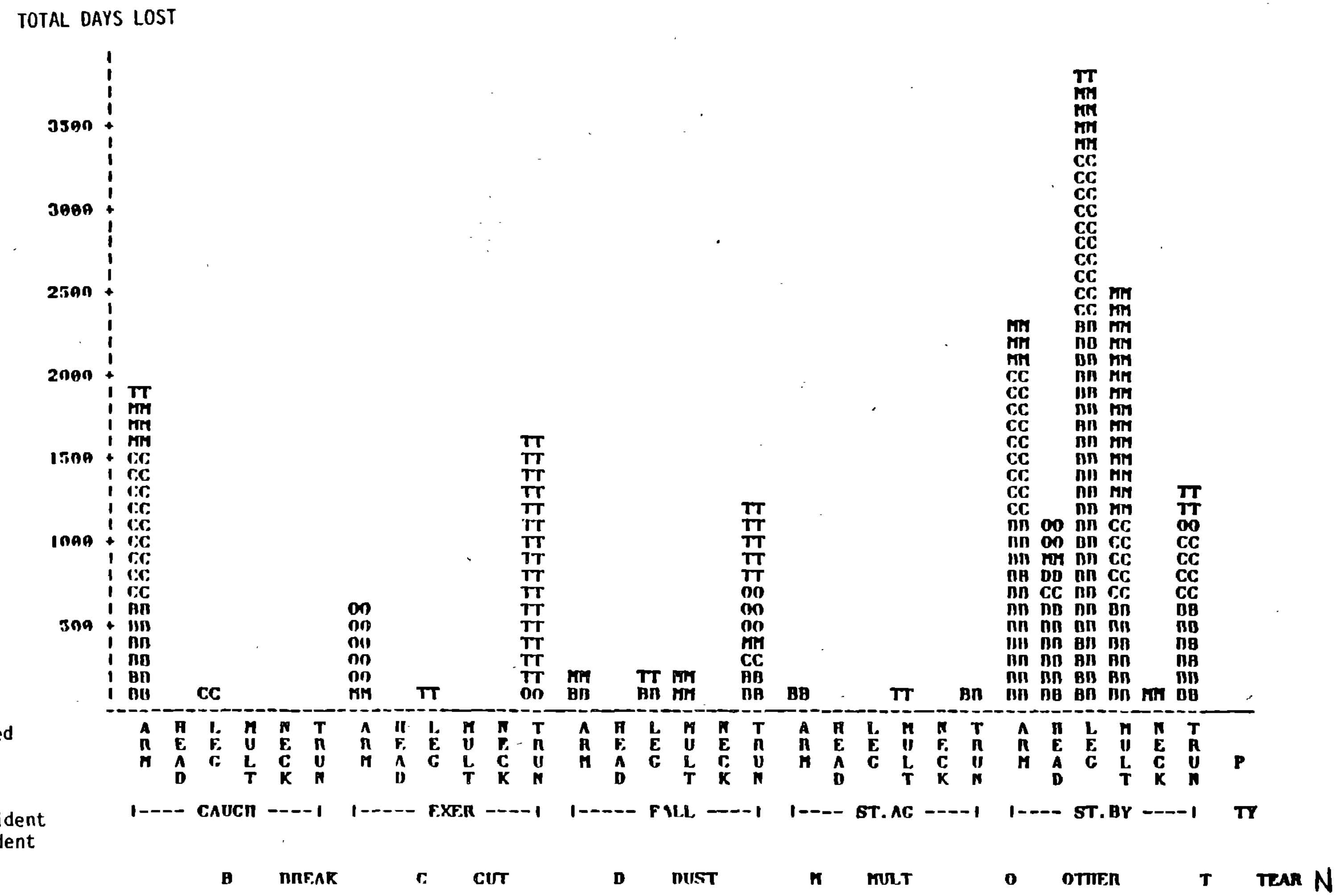
KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-28: Components of MNM JLD accidents as a function of frequency.

METAL: JACKLEG DRILL ACCIDENTS FOR ALL YEARS

BAR CHART OF SUMS



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-29: Components of MNM JLD accidents as a function of days lost.

FIGURE 2-30: Tree diagram of jackleg drill accidents in MNM mines from 1978 to 1983 (N = 1913).

```
CAUGHT  N=310  (0.166)
TDL= 2126  MEAN=  6.69
                 ARM     N=290  (  0.912)
                 TDL= 1084  MEAN=   6.50
                                       BREAK   N= 77   (0.266)   PR=0.0403     DAYS LOST=    7.69
                                       CUT     N=166   (0.572)   PR=0.0869     DAYS LOST=    5.63
                                       MULT    N= 38   (0.131)   PR=0.0199     DAYS LOST=    7.13
                                       OTHER   N=  4   (0.014)   PR=0.0021     DAYS LOST=    6.50
                                       TEAR    N=  5   (0.017)   PR=0.0026     DAYS LOST=   12.00
                 HEAD    N=  3  (0.009)
                 TDL=    59  MEAN= 19.67
                                       CUT     N=  2   (0.667)   PR=0.0010     DAYS LOST=   14.00
                                       MULT    N=  1   (0.333)   PR=0.0005     DAYS LOST=   31.00
                 LEG     N= 12  (0.038)
                 TDL=    96  MEAN=  8.00
                                       BREAK   N=  1   (0.083)   PR=0.0005     DAYS LOST=    0.00
                                       CUT     N=  8   (0.667)   PR=0.0042     DAYS LOST=   10.00
                                       TEAR    N=  3   (0.250)   PR=0.0016     DAYS LOST=    6.33
                 MULT    N=  5  (0.016)
                 TDL=     6  MEAN=  1.20
                                       CUT     N=  1   (0.200)   PR=0.0005     DAYS LOST=    1.00
                                       MULT    N=  2   (0.400)   PR=0.0010     DAYS LOST=    0.00
                                       TEAR    N=  2   (0.400)   PR=0.0010     DAYS LOST=    2.50
                 TRUNK N=  8  (0.025)
                 TDL=    81  MEAN= 10.13
                                       BREAK   N=  1   (0.125)   PR=0.0005     DAYS LOST=   20.00
                                       CUT     N=  4   (0.500)   PR=0.0021     DAYS LOST=    5.75
                                       MULT    N=  1   (0.125)   PR=0.0005     DAYS LOST=    0.00
                                       TEAR    N=  2   (0.250)   PR=0.0010     DAYS LOST=   15.00
EXERTION  N=205  (0.107)
TDL= 2360  MEAN= 11.61
                 ARM     N= 29  (  0.141)
                 TDL=   593  MEAN= 20.45
                                       BREAK   N=  1   (0.034)   PR=0.0005     DAYS LOST=    0.00
                                       MULT    N=  2   (0.069)   PR=0.0010     DAYS LOST=   39.00
                                       OTHER   N= 14   (0.483)   PR=0.0073     DAYS LOST=   33.64
                                       TEAR    N= 12   (0.414)   PR=0.0063     DAYS LOST=    3.67
                 LEG     N=  9  (0.044)
                 TDL=   123  MEAN= 13.67
                                       TEAR    N=  9   (1.000)   PR=0.0047     DAYS LOST=   13.67
                 MULT    N=  4  (0.020)
                 TDL=    10  MEAN=  2.50
                                       TEAR    N=  4   (1.000)   PR=0.0021     DAYS LOST=    2.50
                 NECK  N=  2  (0.010)
                 TDL=    47  MEAN= 23.50
                                       OTHER   N=  1   (0.500)   PR=0.0005     DAYS LOST=    0.00
                                       TEAR    N=  1   (0.500)   PR=0.0005     DAYS LOST=   47.00
                 TRUNK N=161  (0.785)
                 TDL= 1587  MEAN=  9.86
                                       BREAK   N=  1   (0.006)   PR=0.0005     DAYS LOST=    6.00
                                       CUT     N=  3   (0.019)   PR=0.0016     DAYS LOST=    4.00
                                       OTHER   N=  9   (0.056)   PR=0.0047     DAYS LOST=   11.44
                                       TEAR    N=148   (0.919)   PR=0.0774     DAYS LOST=    9.91
FALL N=152  (0.079)
TDL= 1907  MEAN= 12.55
                 ARM     N= 47  (  0.309)
                 TDL=   221  MEAN=  4.70
                                       BREAK   N=  7   (0.149)   PR=0.0037     DAYS LOST=    7.86
                                       CUT     N= 36   (0.766)   PR=0.0188     DAYS LOST=    0.47
                                       MULT    N=  2   (0.043)   PR=0.0010     DAYS LOST=   62.50
                                       TEAR    N=  2   (0.043)   PR=0.0010     DAYS LOST=   12.00
                 HEAD    N=  6  (0.039)
```

```
                          TDL=     9  MEAN=  1.50
                                                   CUT     N=  5  (0.833)  PR=0.0026     DAYS LOST=   1.60
                                                   MULT    N=  1  (0.167)  PR=0.0005     DAYS LOST=   1.00
                          LEG    N= 27  (0.170)
                          TDL=  191  MEAN=  7.07
                                                   BREAK   N=  6  (0.222)  PR=0.0031     DAYS LOST=  15.67
                                                   CUT     N=  5  (0.185)  PR=0.0026     DAYS LOST=   1.40
                                                   MULT    N=  3  (0.111)  PR=0.0016     DAYS LOST=   5.33
                                                   OTHER   N=  4  (0.148)  PR=0.0021     DAYS LOST=   4.00
                                                   TEAR    N=  9  (0.333)  PR=0.0047     DAYS LOST=   6.44
                          MULT   N= 10  (0.066)
                          TDL=  317  MEAN= 31.70
                                                   CUT     N=  2  (0.200)  PR=0.0010     DAYS LOST=  11.50
                                                   MULT    N=  6  (0.600)  PR=0.0031     DAYS LOST=  41.33
                                                   TEAR    N=  2  (0.200)  PR=0.0010     DAYS LOST=  23.00
                          NECK   N=  1  (0.007)
                          TDL=     5  MEAN=  5.00
                                                   TEAR    N=  1  (1.000)  PR=0.0005     DAYS LOST=   5.00
                          TRUNK N= 61  (0.401)
                          TDL= 1164  MEAN= 19.08
                                                   BREAK   N=  7  (0.115)  PR=0.0037     DAYS LOST=  23.71
                                                   CUT     N= 11  (0.180)  PR=0.0058     DAYS LOST=   6.00
                                                   MULT    N=  4  (0.066)  PR=0.0021     DAYS LOST=  20.25
                                                   OTHER   N=  9  (0.148)  PR=0.0047     DAYS LOST=  35.00
                                                   TEAR    N= 30  (0.492)  PR=0.0157     DAYS LOST=  17.87
STAG N= 45  (0.024)
TDL=  326  MEAN=  7.24
                          ARM    N= 25  (  0.556)
                          TDL=  101  MEAN=  4.04
                                                   BREAK   N=  2  (0.080)  PR=0.0010     DAYS LOST=  41.00
                                                   CUT     N= 21  (0.840)  PR=0.0110     DAYS LOST=   0.71
                                                   OTHER   N=  2  (0.080)  PR=0.0010     DAYS LOST=   2.00
                          HEAD   N=  6  (0.133)
                          TDL=   42  MEAN=  7.00
                                                   BREAK   N=  1  (0.167)  PR=0.0005     DAYS LOST=   1.00
                                                   CUT     N=  5  (0.833)  PR=0.0026     DAYS LOST=   8.20
                          LEG    N=  7  (0.156)
                          TDL=   32  MEAN=  4.57
                                                   CUT     N=  3  (0.429)  PR=0.0016     DAYS LOST=   0.00
                                                   TEAR    N=  4  (0.571)  PR=0.0021     DAYS LOST=   8.00
                          MULT   N=  3  (0.067)
                          TDL=   75  MEAN= 25.00
                                                   MULT    N=  1  (0.333)  PR=0.0005     DAYS LOST=   2.00
                                                   TEAR    N=  2  (0.667)  PR=0.0010     DAYS LOST=  36.50
                          TRUNK N=  4  (0.089)
                          TDL=   76  MEAN= 19.00
                                                   BREAK   N=  1  (0.250)  PR=0.0005     DAYS LOST=  67.00
                                                   CUT     N=  1  (0.250)  PR=0.0005     DAYS LOST=   0.00
                                                   MULT    N=  1  (0.250)  PR=0.0005     DAYS LOST=   9.00
                                                   TEAR    N=  1  (0.250)  PR=0.0005     DAYS LOST=   0.00
STBY N=1193  (0.624)
TDL=11329  MEAN=  9.50
                          ARM    N=470  (  0.394)
                          TDL= 2311  MEAN=  4.92
                                                   BREAK   N= 72  (0.153)  PR=0.0376     DAYS LOST=  15.24
                                                   CUT     N=357  (0.760)  PR=0.1866     DAYS LOST=   2.49
                                                   MULT    N= 33  (0.070)  PR=0.0173     DAYS LOST=   7.85
                                                   OTHER   N=  4  (0.009)  PR=0.0021     DAYS LOST=  12.25
                                                   TEAR    N=  4  (0.009)  PR=0.0021     DAYS LOST=   4.50
                          HEAD   N=259  (0.217)
                          TDL= 1058  MEAN=  4.08
                                                   BREAK   N= 23  (0.089)  PR=0.0120     DAYS LOST=  27.39
                                                   CUT     N=139  (0.537)  PR=0.0727     DAYS LOST=   0.75
                                                   DUST    N= 61  (0.236)  PR=0.0319     DAYS LOST=   1.44
                                                   MULT    N= 21  (0.081)  PR=0.0110     DAYS LOST=   3.81
                                                   OTHER   N= 15  (0.058)  PR=0.0078     DAYS LOST=  10.40
```

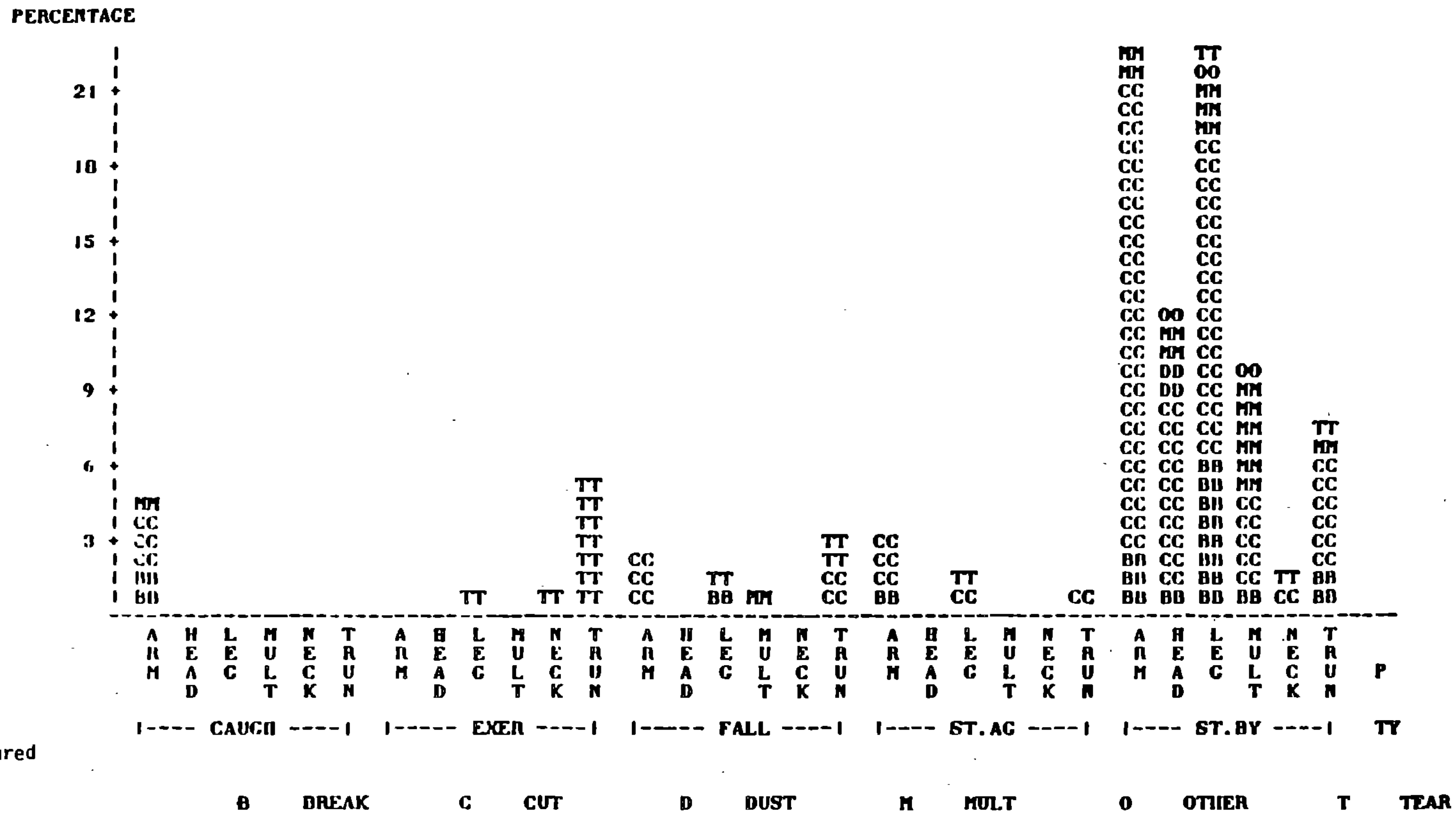
```
LEG    N=277  (0.232)
TDL= 3898  MEAN= 14.07
                      BREAK  N= 56  (0.202)  PR=0.0293   DAYS LOST=  41.63
                      CUT    N=175  (0.632)  PR=0.0915   DAYS LOST=   5.70
                      MULT   N= 27  (0.097)  PR=0.0141   DAYS LOST=  15.00
                      OTHER  N=  8  (0.029)  PR=0.0042   DAYS LOST=   3.88
                      TEAR   N= 11  (0.040)  PR=0.0058   DAYS LOST=  12.09
MULT   N= 70  (0.059)
TDL= 2618  MEAN= 37.40
                      BREAK  N=  4  (0.057)  PR=0.0021   DAYS LOST= 157.25
                      CUT    N= 24  (0.343)  PR=0.0125   DAYS LOST=  22.46
                      MULT   N= 39  (0.557)  PR=0.0204   DAYS LOST=  36.90
                      OTHER  N=  3  (0.043)  PR=0.0016   DAYS LOST=   3.67
NECK  N= 20  (0.017)
TDL=  101  MEAN=  5.05
                      BREAK  N=  2  (0.100)  PR=0.0010   DAYS LOST=  12.00
                      CUT    N=  7  (0.350)  PR=0.0037   DAYS LOST=   1.57
                      MULT   N=  2  (0.100)  PR=0.0010   DAYS LOST=  29.50
                      OTHER  N=  3  (0.150)  PR=0.0016   DAYS LOST=   0.33
                      TEAR   N=  6  (0.300)  PR=0.0031   DAYS LOST=   1.00
TRUNK N= 97  (0.081)
TDL= 1343  MEAN= 13.85
                      BREAK  N= 22  (0.227)  PR=0.0115   DAYS LOST=  28.18
                      CUT    N= 58  (0.598)  PR=0.0303   DAYS LOST=   7.21
                      MULT   N=  2  (0.021)  PR=0.0010   DAYS LOST=   4.50
                      OTHER  N=  7  (0.072)  PR=0.0037   DAYS LOST=  17.29
                      TEAR   N=  8  (0.082)  PR=0.0042   DAYS LOST=  21.88

TOTAL  DAYS  LOST  =  10040

AVERAGE DAYS LOST  =   9.434
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

METAL: SCALING BAR ACCIDENTS FOR ALL YEARS

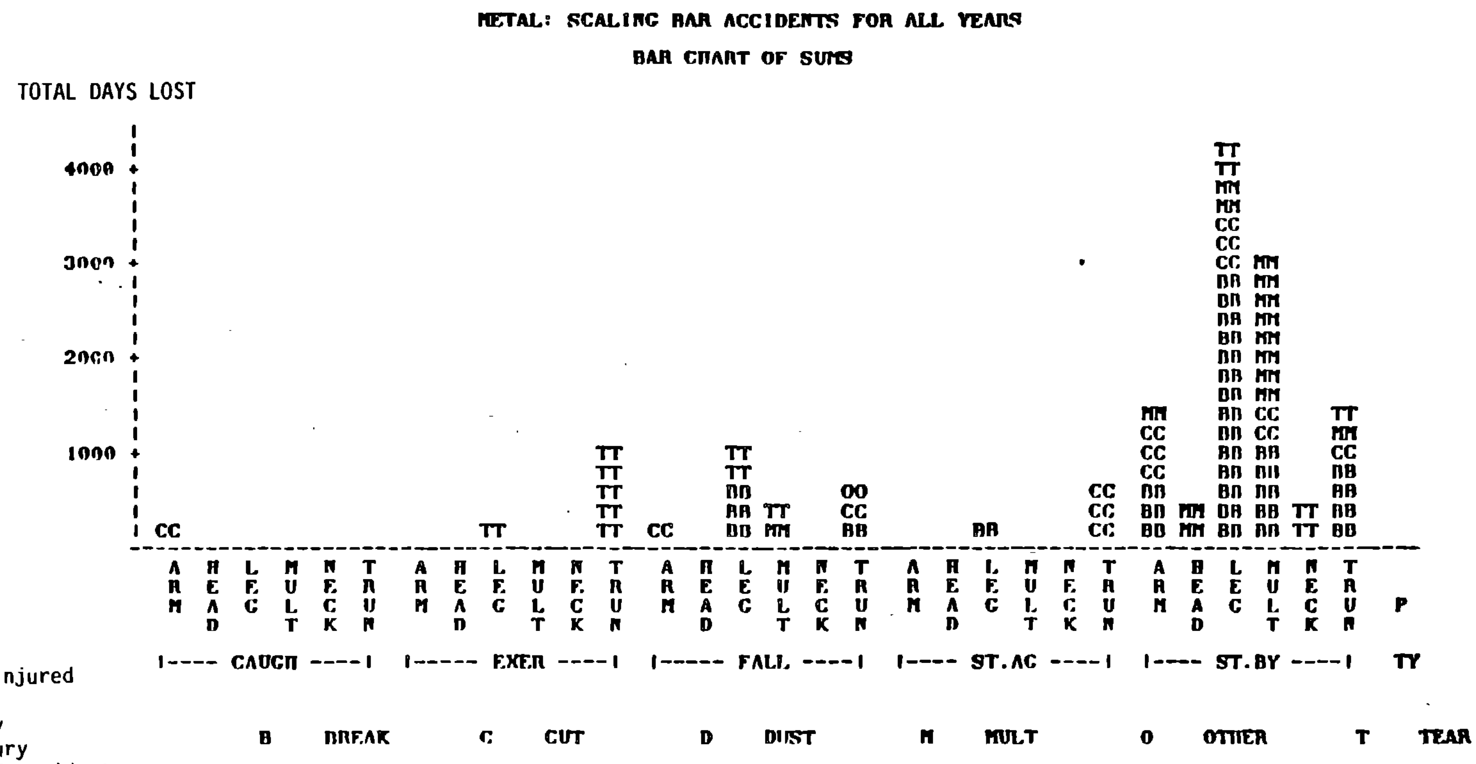
PERCENTAGE BAR CHART



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-31: Components of MNM scaling bar accidents as a function of frequency.



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-32: Components of MNM scaling bar accidents as a function of lost days.

FIGURE 2-33: Tree diagram of scaling bar accidents in MNM mines from 1978 to 1983 (N = 1033).

```
CAUGHT  N= 48  (0.046)
TDL=  323  MEAN=  6.73
                          ARM    N= 44  (  0.917)
                          TDL=  278  MEAN=  6.32
                                            BREAK  N= 14  (0.318)  PR=0.0136     DAYS LOST=   3.71
                                            CUT    N= 24  (0.545)  PR=0.0232     DAYS LOST=   8.25
                                            MULT   N=  6  (0.136)  PR=0.0058     DAYS LOST=   4.67
                          HEAD   N=  2  (0.042)
                          TDL=    0  MEAN=  0.00
                                            BREAK  N=  1  (0.500)  PR=0.0010     DAYS LOST=   0.00
                                            CUT    N=  1  (0.500)  PR=0.0010     DAYS LOST=   0.00
                          LEG    N=  2  (0.042)
                          TDL=   45  MEAN= 22.50
                                            CUT    N=  2  (1.000)  PR=0.0019     DAYS LOST=  22.50
EXERTION  N= 67  (0.065)
TDL= 1346  MEAN= 20.09
                          ARM    N=  3  (  0.045)
                          TDL=   32  MEAN= 10.67
                                            CUT    N=  1  (0.333)  PR=0.0010     DAYS LOST=   0.00
                                            TEAR   N=  2  (0.667)  PR=0.0019     DAYS LOST=  16.00
                          LEG    N=  6  (0.090)
                          TDL=  214  MEAN= 35.67
                                            TEAR   N=  6  (1.000)  PR=0.0058     DAYS LOST=  35.67
                          MULT   N=  1  (0.015)
                          TDL=   92  MEAN= 92.00
                                            OTHER  N=  1  (1.000)  PR=0.0010     DAYS LOST=  92.00
                          NECK  N=  4  (0.060)
                          TDL=    1  MEAN=  0.25
                                            TEAR   N=  4  (1.000)  PR=0.0039     DAYS LOST=   0.25
                          TRUNK N= 53  (0.791)
                          TDL= 1007  MEAN= 19.00
                                            OTHER  N=  1  (0.019)  PR=0.0010     DAYS LOST=   2.00
                                            TEAR   N= 52  (0.981)  PR=0.0503     DAYS LOST=  19.33
FALL N= 89  (0.086)
TDL= 2465  MEAN= 27.70
                          ARM    N= 28  (  0.315)
                          TDL=  313  MEAN= 11.18
                                            BREAK  N=  1  (0.036)  PR=0.0010     DAYS LOST=  61.00
                                            CUT    N= 25  (0.893)  PR=0.0242     DAYS LOST=   9.72
                                            MULT   N=  2  (0.071)  PR=0.0019     DAYS LOST=   4.50
                          LEG    N= 21  (0.236)
                          TDL= 1021  MEAN= 48.62
                                            BREAK  N=  6  (0.286)  PR=0.0058     DAYS LOST=  98.67
                                            CUT    N=  3  (0.143)  PR=0.0029     DAYS LOST=  21.67
                                            MULT   N=  1  (0.048)  PR=0.0010     DAYS LOST=  29.00
                                            TEAR   N= 11  (0.524)  PR=0.0106     DAYS LOST=  30.45
                          MULT   N= 11  (0.124)
                          TDL=  313  MEAN= 28.45
                                            CUT    N=  2  (0.182)  PR=0.0019     DAYS LOST=   6.50
                                            MULT   N=  5  (0.455)  PR=0.0048     DAYS LOST=  38.20
                                            OTHER  N=  2  (0.182)  PR=0.0019     DAYS LOST=   0.00
                                            TEAR   N=  2  (0.182)  PR=0.0019     DAYS LOST=  54.50
                          NECK  N=  1  (0.011)
                          TDL=   23  MEAN= 23.00
                                            TEAR   N=  1  (1.000)  PR=0.0010     DAYS LOST=  23.00
                          TRUNK N= 28  (0.315)
                          TDL=  795  MEAN= 28.39
                                            BREAK  N=  1  (0.036)  PR=0.0010     DAYS LOST= 221.00
                                            CUT    N= 12  (0.429)  PR=0.0116     DAYS LOST=  15.33
                                            MULT   N=  1  (0.036)  PR=0.0010     DAYS LOST=  56.00
                                            OTHER  N=  2  (0.071)  PR=0.0019     DAYS LOST= 124.50
                                            TEAR   N= 12  (0.429)  PR=0.0116     DAYS LOST=   7.00
```

```
STAG N= 55  (0.053)
TDL= 1078  MEAN= 19.60
                    ARM    N= 31  (  0.564)
                    TDL=    74  MEAN=   2.39
                                        BREAK   N=  5   (0.161)   PR=0.0048      DAYS LOST=    6.00
                                        CUT     N= 23   (0.742)   PR=0.0223      DAYS LOST=    1.39
                                        MULT    N=  1   (0.032)   PR=0.0010      DAYS LOST=    0.00
                                        OTHER   N=  1   (0.032)   PR=0.0010      DAYS LOST=    4.00
                                        TEAR    N=  1   (0.032)   PR=0.0010      DAYS LOST=    4.00
                    HEAD   N=  2  (0.036)
                    TDL=    10  MEAN=   5.00
                                        CUT     N=  1   (0.500)   PR=0.0010      DAYS LOST=    4.00
                                        OTHER   N=  1   (0.500)   PR=0.0010      DAYS LOST=    6.00
                    LEG    N= 12  (0.218)
                    TDL=   256  MEAN=  21.33
                                        BREAK   N=  2   (0.167)   PR=0.0019      DAYS LOST=  122.00
                                        CUT     N=  6   (0.500)   PR=0.0058      DAYS LOST=    1.67
                                        TEAR    N=  4   (0.333)   PR=0.0039      DAYS LOST=    0.50
                    MULT   N=  4  (0.073)
                    TDL=   117  MEAN=  29.25
                                        CUT     N=  2   (0.500)   PR=0.0019      DAYS LOST=   14.00
                                        MULT    N=  1   (0.250)   PR=0.0010      DAYS LOST=   83.00
                                        TEAR    N=  1   (0.250)   PR=0.0010      DAYS LOST=    6.00
                    NECK   N=  1  (0.018)
                    TDL=     0  MEAN=   0.00
                                        TEAR    N=  1   (1.000)   PR=0.0010      DAYS LOST=    0.00
                    TRUNK  N=  5  (0.091)
                    TDL=   621  MEAN=124.20
                                        CUT     N=  4   (0.800)   PR=0.0039      DAYS LOST=  154.25
                                        TEAR    N=  1   (0.200)   PR=0.0010      DAYS LOST=    4.00

STBY N=774  (0.749)
TDL=11334  MEAN= 14.64
                    ARM    N=236  (  0.305)
                    TDL=  1394  MEAN=   5.91
                                        BREAK   N= 21   (0.089)   PR=0.0203      DAYS LOST=   32.19
                                        CUT     N=190   (0.805)   PR=0.1839      DAYS LOST=    3.14
                                        MULT    N= 17   (0.072)   PR=0.0165      DAYS LOST=    6.41
                                        OTHER   N=  4   (0.017)   PR=0.0039      DAYS LOST=    0.25
                                        TEAR    N=  4   (0.017)   PR=0.0039      DAYS LOST=    2.75
                    HEAD   N=116  (0.150)
                    TDL=   447  MEAN=   3.85
                                        BREAK   N= 11   (0.095)   PR=0.0106      DAYS LOST=    3.55
                                        CUT     N= 74   (0.638)   PR=0.0716      DAYS LOST=    0.89
                                        DUST    N= 14   (0.121)   PR=0.0136      DAYS LOST=    2.21
                                        MULT    N= 12   (0.103)   PR=0.0116      DAYS LOST=   25.75
                                        OTHER   N=  5   (0.043)   PR=0.0048      DAYS LOST=    0.40
                    LEG    N=226  (0.292)
                    TDL=  4402  MEAN=  19.48
                                        BREAK   N= 61   (0.270)   PR=0.0591      DAYS LOST=   47.43
                                        CUT     N=129   (0.571)   PR=0.1249      DAYS LOST=    5.05
                                        MULT    N= 25   (0.111)   PR=0.0242      DAYS LOST=   19.36
                                        OTHER   N=  5   (0.022)   PR=0.0048      DAYS LOST=    9.80
                                        TEAR    N=  6   (0.027)   PR=0.0058      DAYS LOST=   54.00
                    MULT   N= 96  (0.124)
                    TDL=  3207  MEAN=  33.41
                                        BREAK   N= 10   (0.104)   PR=0.0097      DAYS LOST=  100.30
                                        CUT     N= 35   (0.365)   PR=0.0339      DAYS LOST=   13.60
                                        MULT    N= 43   (0.448)   PR=0.0416      DAYS LOST=   37.70
                                        OTHER   N=  6   (0.063)   PR=0.0058      DAYS LOST=    4.83
                                        TEAR    N=  2   (0.021)   PR=0.0019      DAYS LOST=   39.00
                    NECK   N= 17  (0.022)
                    TDL=   395  MEAN=  23.24
                                        BREAK   N=  2   (0.118)   PR=0.0019      DAYS LOST=   18.50
                                        CUT     N=  4   (0.235)   PR=0.0039      DAYS LOST=    0.00
                                        MULT    N=  1   (0.059)   PR=0.0010      DAYS LOST=   16.00
                                        OTHER   N=  1   (0.059)   PR=0.0010      DAYS LOST=    0.00
                                        TEAR    N=  9   (0.529)   PR=0.0087      DAYS LOST=   38.00
```

TRUNK N= 83 (0.107)
TDL= 1489 MEAN= 17.94

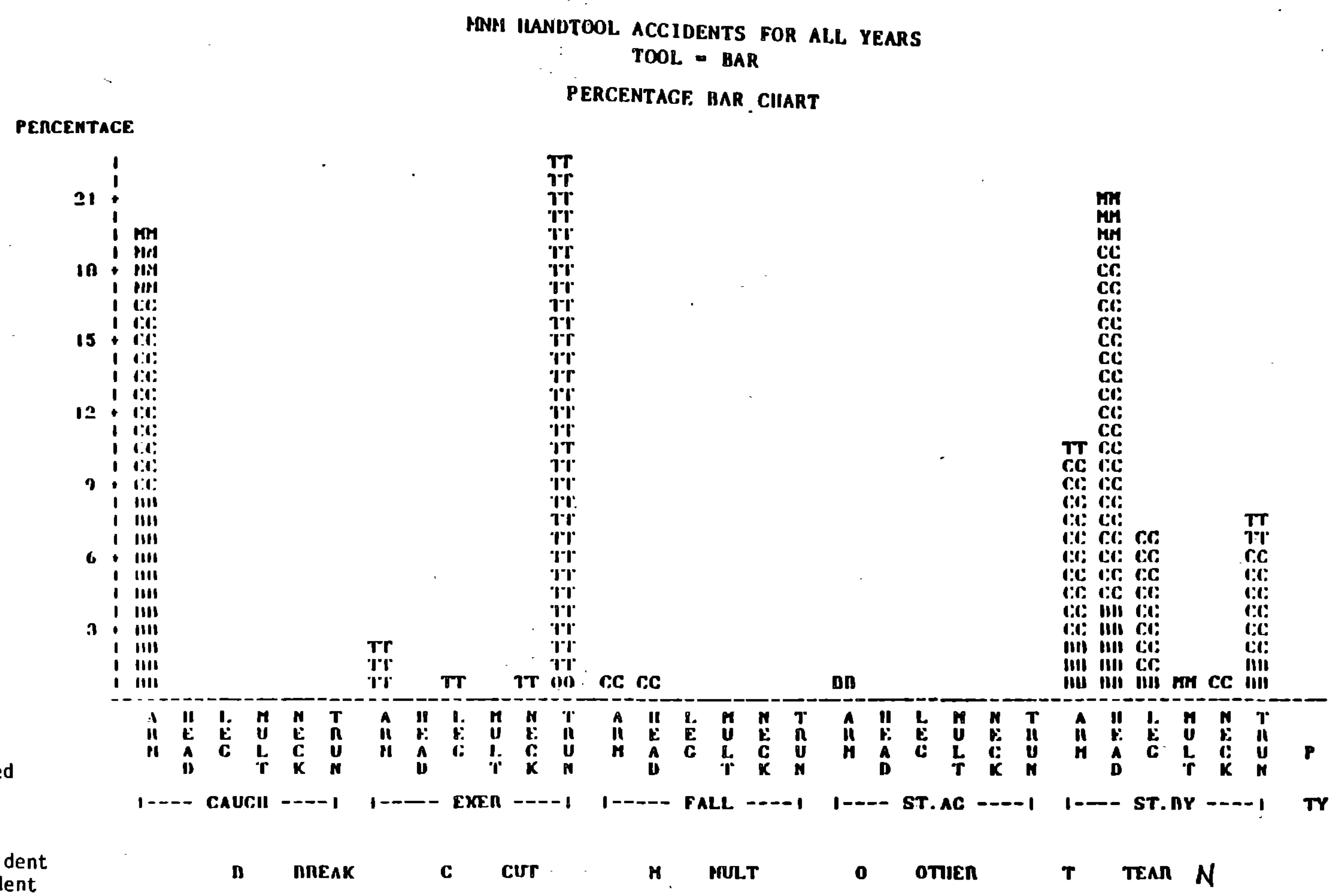
BREAK	N= 10	(0.217)	PR=0.0174	DAYS LOST=	45.44
CUT	N= 44	(0.530)	PR=0.0426	DAYS LOST=	4.73
MULT	N= 10	(0.120)	PR=0.0097	DAYS LOST=	26.20
OTHER	N= 2	(0.024)	PR=0.0019	DAYS LOST=	20.50
TEAR	N= 9	(0.100)	PR=0.0087	DAYS LOST=	17.78

TOTAL DAYS LOST = 16546

AVERAGE DAYS LOST = 16.017

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

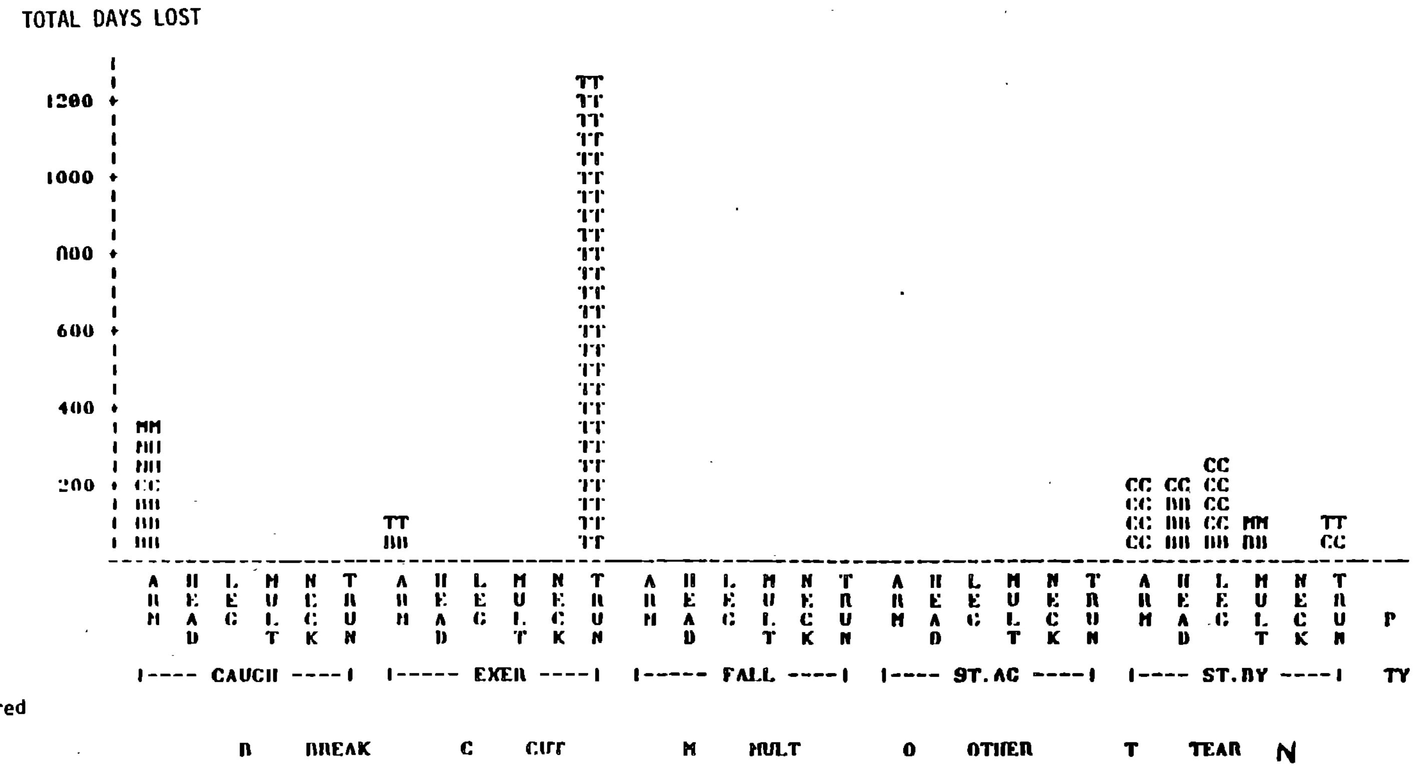


KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-34: Components of MNM bar accidents as a function of frequency.

MNM HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = BAR
BAR CHART OF SUMS



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-35: Components of MNM bar accidents as a function of days lost.

FIGURE 2-36: Tree diagram of pry bar accidents in MNM mines from 1978 to 1983 (N = 397).

```
CAUGHT  N-  80  ( 0.201)
TDL-  338  MEAN- 4.22
                         ARM     N-   78  ( 0.975)
                         TDL-   338  MEAN- 4.33
                                            BREAK   N- 32   (0.410)   PR- 0.0804      DAYS LOST-   4.75
                                            CUT     N- 33   (0.423)   PR- 0.0829      DAYS LOST-   1.64
                                            MULT    N- 12   (0.154)   PR- 0.0302      DAYS LOST-  11.00
                                            OTHER   N-  1   (0.013)   PR- 0.0025      DAYS LOST-   0.00
                         HEAD    N-    1  ( 0.012)
                         TDL-     0  MEAN- 0.00
                                            CUT     N-  1   (1.000)   PR- 0.0025      DAYS LOST-   0.00
                         LEG     N-    1  ( 0.012)
                         TDL-     0  MEAN- 0.00
                                            CUT     N-  1   (1.000)   PR- 0.0025      DAYS LOST-   0.00

EXERTION  N- 104  ( 0.261)
TDL- 1432  MEAN-13.77
                         ARM     N-   10  ( 0.096)
                         TDL-   109  MEAN-10.90
                                            BREAK   N-  1   (0.100)   PR- 0.0025      DAYS LOST-  51.00
                                            CUT     N-  1   (0.100)   PR- 0.0025      DAYS LOST-   0.00
                                            TEAR    N-  8   (0.800)   PR- 0.0201      DAYS LOST-   7.25
                         LEG     N-    2  ( 0.019)
                         TDL-    24  MEAN-12.00
                                            TEAR    N-  2   (1.000)   PR- 0.0050      DAYS LOST-  12.00
                         NECK  N-     2  ( 0.019)
                         TDL-     1  MEAN- 0.50
                                            TEAR    N-  2   (1.000)   PR- 0.0050      DAYS LOST-   0.50
                         TRUNK N-    90  ( 0.865)
                         TDL- 1298  MEAN-14.42
                                            CUT     N-  1   (0.011)   PR- 0.0025      DAYS LOST-   0.00
                                            OTHER   N-  3   (0.033)   PR- 0.0075      DAYS LOST-   8.00
                                            TEAR    N- 86   (0.956)   PR- 0.2161      DAYS LOST-  14.81

FALL N-    9  ( 0.023)
TDL-    36  MEAN- 4.00
                         ARM     N-    2  ( 0.222)
                         TDL-     0  MEAN- 0.00
                                            CUT     N-  2   (1.000)   PR- 0.0050      DAYS LOST-   0.00
                         HEAD    N-    2  ( 0.222)
                         TDL-     5  MEAN- 2.50
                                            CUT     N-  2   (1.000)   PR- 0.0050      DAYS LOST-   2.50
                         LEG     N-    1  ( 0.111)
                         TDL-     0  MEAN- 0.00
                                            CUT     N-  1   (1.000)   PR- 0.0025      DAYS LOST-   0.00
                         MULT    N-    1  ( 0.111)
                         TDL-    11  MEAN-11.00
                                            CUT     N-  1   (1.000)   PR- 0.0025      DAYS LOST-  11.00
                         TRUNK N-     3  ( 0.333)
                         TDL-    20  MEAN- 6.67
                                            CUT     N-  1   (0.333)   PR- 0.0025      DAYS LOST-   3.00
                                            OTHER   N-  1   (0.333)   PR- 0.0025      DAYS LOST-  17.00
                                            TEAR    N-  1   (0.333)   PR- 0.0025      DAYS LOST-   0.00

STAG N-   5  ( 0.013)
TDL-     5  MEAN- 1.00
                         ARM     N-    3  ( 0.600)
                         TDL-     0  MEAN- 0.00
                                            BREAK   N-  3   (1.000)   PR- 0.0075      DAYS LOST-   0.00
                         HEAD    N-    1  ( 0.200)
                         TDL-     0  MEAN- 0.00
                                            CUT     N-  1   (1.000)   PR- 0.0025      DAYS LOST-   0.00
                         LEG     N-    1  ( 0.200)
                         TDL-     5  MEAN- 5.00
```

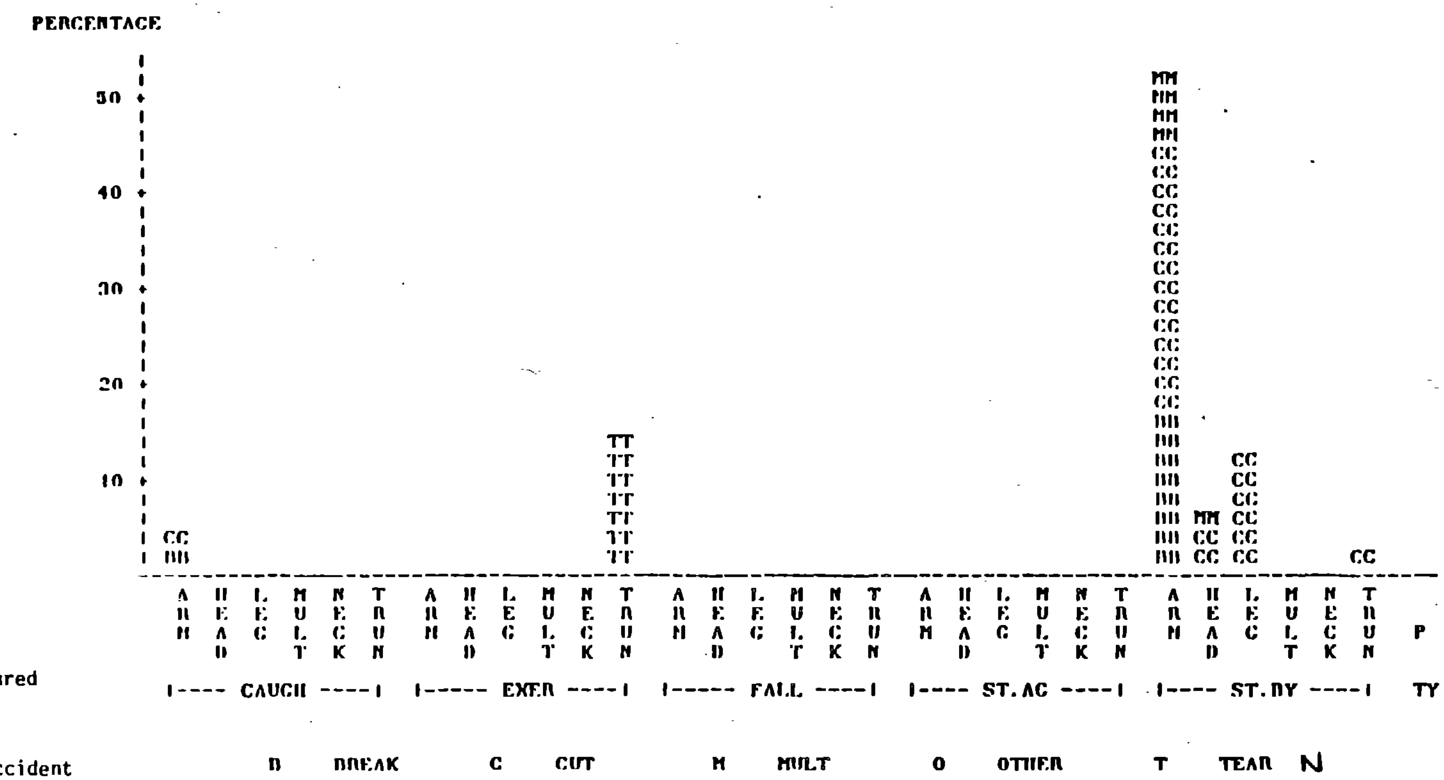
```
                                                   CUT    N=  1  (1.000)  PR= 0.0025    DAYS LOST=   5.00
STBY N= 199  ( 0.500)
TDL=  852  MEAN= 4.20
                        ARM    N=  44  ( 0.221)
                        TDL=  212  MEAN= 4.82
                                                   BREAK  N= 10  (0.227)  PR= 0.0251    DAYS LOST=   2.30
                                                   CUT    N= 30  (0.682)  PR= 0.0764    DAYS LOST=   5.90
                                                   OTHER  N=  1  (0.023)  PR= 0.0025    DAYS LOST=   1.00
                                                   TEAR   N=  3  (0.068)  PR= 0.0076    DAYS LOST=   3.67
                        HEAD   N=  85  ( 0.427)
                        TDL=  180  MEAN= 2.12
                                                   BREAK  N= 14  (0.165)  PR= 0.0352    DAYS LOST=   9.71
                                                   CUT    N= 60  (0.706)  PR= 0.1500    DAYS LOST=   0.47
                                                   MULT   N= 10  (0.118)  PR= 0.0251    DAYS LOST=   0.00
                                                   OTHER  N=  1  (0.012)  PR= 0.0025    DAYS LOST=  16.00
                        LEG    N=  28  ( 0.141)
                        TDL=  281  MEAN=10.04
                                                   BREAK  N=  2  (0.071)  PR= 0.0050    DAYS LOST=  26.50
                                                   CUT    N= 24  (0.857)  PR= 0.0603    DAYS LOST=   8.83
                                                   MULT   N=  1  (0.036)  PR= 0.0025    DAYS LOST=   2.00
                                                   OTHER  N=  1  (0.036)  PR= 0.0025    DAYS LOST=  14.00
                        MULT   N=   5  ( 0.025)
                        TDL=   84  MEAN=16.80
                                                   BREAK  N=  1  (0.200)  PR= 0.0025    DAYS LOST=  46.00
                                                   CUT    N=  1  (0.200)  PR= 0.0025    DAYS LOST=   0.00
                                                   MULT   N=  2  (0.400)  PR= 0.0050    DAYS LOST=  15.50
                                                   OTHER  N=  1  (0.200)  PR= 0.0025    DAYS LOST=   7.00
                        NECK   N=   4  ( 0.020)
                        TDL=   19  MEAN= 4.75
                                                   CUT    N=  2  (0.500)  PR= 0.0050    DAYS LOST=   0.00
                                                   MULT   N=  1  (0.250)  PR= 0.0025    DAYS LOST=  16.00
                                                   TEAR   N=  1  (0.250)  PR= 0.0025    DAYS LOST=   3.00
                        TRUNK  N=  33  ( 0.166)
                        TDL=   76  MEAN= 2.30
                                                   BREAK  N=  7  (0.212)  PR= 0.0176    DAYS LOST=   1.57
                                                   CUT    N= 19  (0.576)  PR= 0.0477    DAYS LOST=   1.74
                                                   OTHER  N=  1  (0.030)  PR= 0.0025    DAYS LOST=   3.00
                                                   TEAR   N=  6  (0.182)  PR= 0.0151    DAYS LOST=   4.83
          TOTAL  DAYS  LOST  =   2663

          AVERAGE DAYS LOST  =   6.691
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

MNM HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = HAMMER/AXE

PERCENTAGE BAR CHART

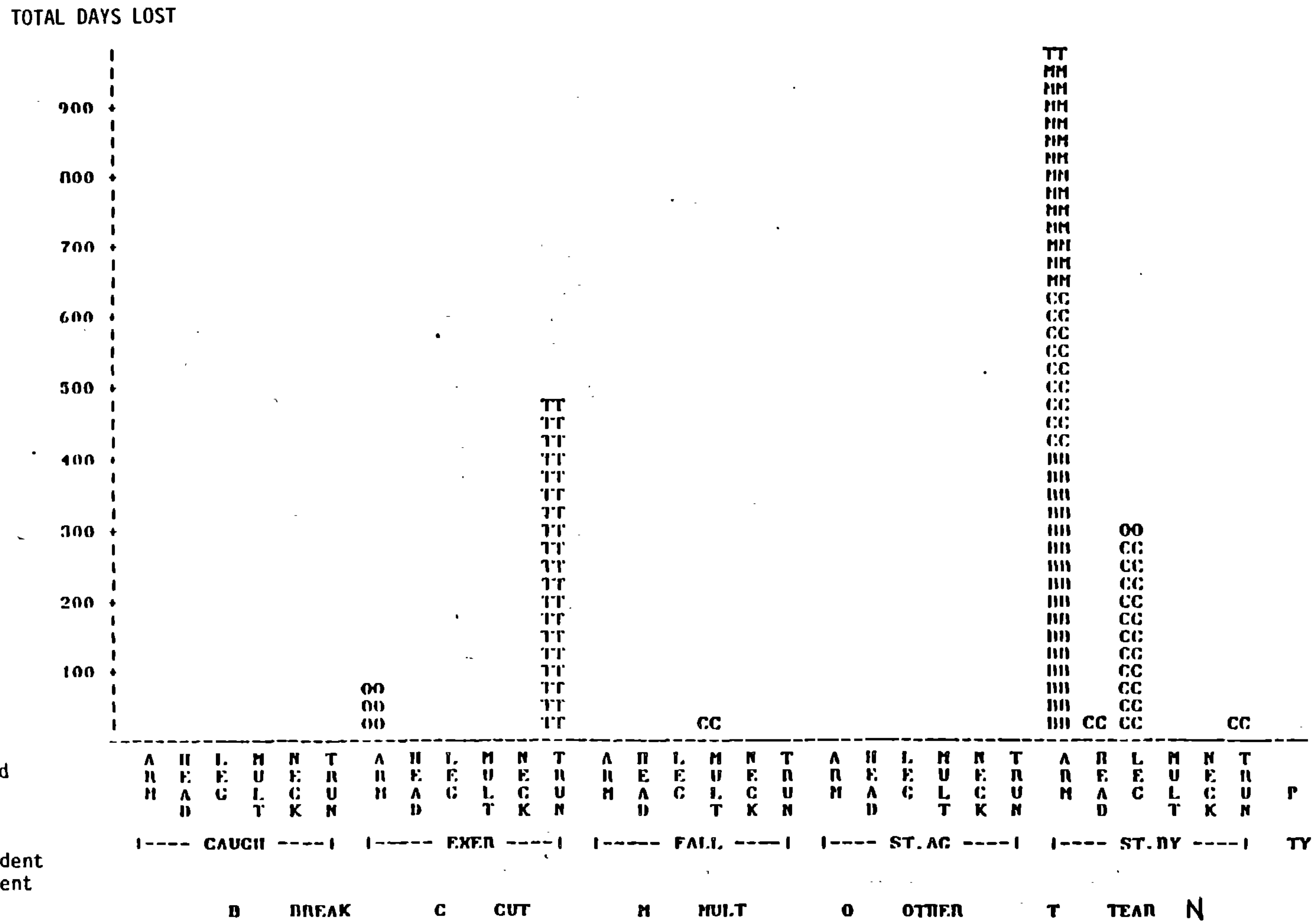


KEY
P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-37: Components of MNM axe/hammer accidents as a function of frequency.

MNM HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = HAMMER/AXE

BAR CHART OF SUMS



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-38: Components of MNM axe/hammer accidents as a function of days lost.

FIGURE 2-39: Tree diagram of axe/hammer accidents in MNM mines from 1978 to 1983 (N = 405).

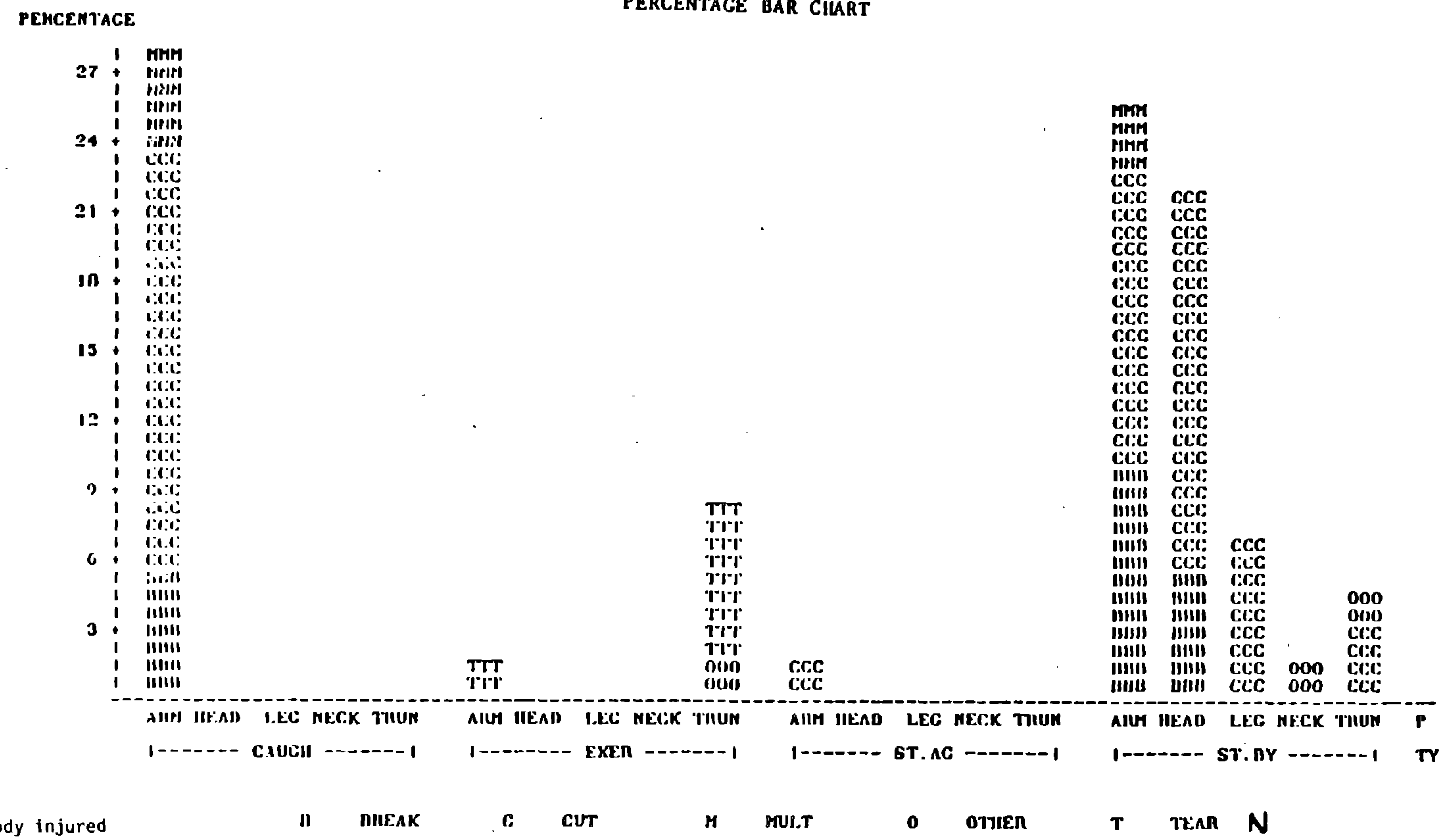
```
CAUGHT  N=  16  ( 0.039)
TDL=     4  MEAN= 0.25
                        ARM    N=  15  ( 0.938)
                        TDL=    4  MEAN= 0.27
                                         BREAK  N=  5  (0.333)  PR= 0.0123    DAYS LOST=    0.00
                                         CUT    N=  7  (0.467)  PR= 0.0172    DAYS LOST=    0.00
                                         MULT   N=  2  (0.133)  PR= 0.0049    DAYS LOST=    0.00
                                         TEAR   N=  1  (0.067)  PR= 0.0025    DAYS LOST=    0.00
                        LEG    N=   1  ( 0.063)
                        TDL=    0  MEAN= 0.00
                                         BREAK  N=  1  (1.000)  PR= 0.0025    DAYS LOST=    0.00

EXERTION  N=  67  ( 0.165)
TDL=  540  MEAN= 8.18
                        ARM    N=   8  ( 0.119)
                        TDL=   84  MEAN=10.50
                                         OTHER  N=  4  (0.500)  PR= 0.0099    DAYS LOST=   19.50
                                         TEAR   N=  4  (0.500)  PR= 0.0099    DAYS LOST=    1.50
                        NECK  N=   1  ( 0.015)
                        TDL=    0  MEAN= 0.00
                                         TEAR   N=  1  (1.000)  PR= 0.0025    DAYS LOST=    0.00
                        TRUNK N=  58  ( 0.066)
                        TDL=  464  MEAN= 0.00
                                         OTHER  N=  2  (0.034)  PR= 0.0049    DAYS LOST=    0.00
                                         TEAR   N= 56  (0.966)  PR= 0.1379    DAYS LOST=    8.29

FALL N=   3  ( 0.007)
TDL=   29  MEAN= 9.67
                        ARM    N=   1  ( 0.333)
                        TDL=    0  MEAN= 0.00
                                         CUT    N=  1  (1.000)  PR= 0.0025    DAYS LOST=    0.00
                        HEAD   N=   1  ( 0.333)
                        TDL=    0  MEAN= 0.00
                                         CUT    N=  1  (1.000)  PR= 0.0025    DAYS LOST=    0.00
                        MULT   N=   1  ( 0.333)
                        TDL=   29  MEAN=29.00
                                         CUT    N=  1  (1.000)  PR= 0.0025    DAYS LOST=   29.00

STAG N=   7  ( 0.017)
TDL=    7  MEAN= 1.00
                        ARM    N=   6  ( 0.857)
                        TDL=    7  MEAN= 1.17
                                         BREAK  N=  1  (0.167)  PR= 0.0025    DAYS LOST=    7.00
                                         CUT    N=  4  (0.667)  PR= 0.0099    DAYS LOST=    0.00
                                         TEAR   N=  1  (0.167)  PR= 0.0025    DAYS LOST=    0.00
                        LEG    N=   1  ( 0.143)
                        TDL=    0  MEAN= 0.00
                                         CUT    N=  1  (1.000)  PR= 0.0025    DAYS LOST=    0.00

STBY N= 312  ( 0.768)
TDL= 1314  MEAN= 4.21
                        ARM    N= 219  ( 0.702)
                        TDL=  978  MEAN= 4.47
                                         BREAK  N= 68  (0.311)  PR= 0.1675    DAYS LOST=    6.00
                                         CUT    N=113  (0.516)  PR= 0.2783    DAYS LOST=    1.95
                                         MULT   N= 32  (0.146)  PR= 0.0788    DAYS LOST=   10.41
                                         OTHER  N=  3  (0.014)  PR= 0.0074    DAYS LOST=    1.00
                                         TEAR   N=  3  (0.014)  PR= 0.0074    DAYS LOST=    4.67
                        HEAD   N=  29  ( 0.093)
                        TDL=   23  MEAN= 0.79
                                         BREAK  N=  3  (0.103)  PR= 0.0074    DAYS LOST=    0.00
                                         CUT    N= 20  (0.690)  PR= 0.0493    DAYS LOST=    0.75
                                         MULT   N=  5  (0.172)  PR= 0.0123    DAYS LOST=    1.60
                                         OTHER  N=  1  (0.034)  PR= 0.0025    DAYS LOST=    0.00
                        LEG    N=  53  ( 0.170)
                        TDL=  291  MEAN= 5.49
```

```
                                 CUT    N= 48  (0.906)  PR= 0.1102    DAYS LOST=  5.69
                                 MULT   N=  2  (0.038)  PR= 0.0049    DAYS LOST=  2.00
                                 OTHER  N=  2  (0.030)  PR= 0.0049    DAYS LOST=  7.00
                                 TEAR   N=  1  (0.019)  PR= 0.0025    DAYS LOST=  0.00
                TRUNK N=  11  ( 0.035)
                TDL=   22  MEAN= 2.00
                                 CUT    N=  9  (0.818)  PR= 0.0222    DAYS LOST=  2.33
                                 OTHER  N=  2  (0.102)  PR= 0.0049    DAYS LOST=  0.50

TOTAL DAYS LOST  =   1902

AVERAGE DAYS LOST  =   4.605
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

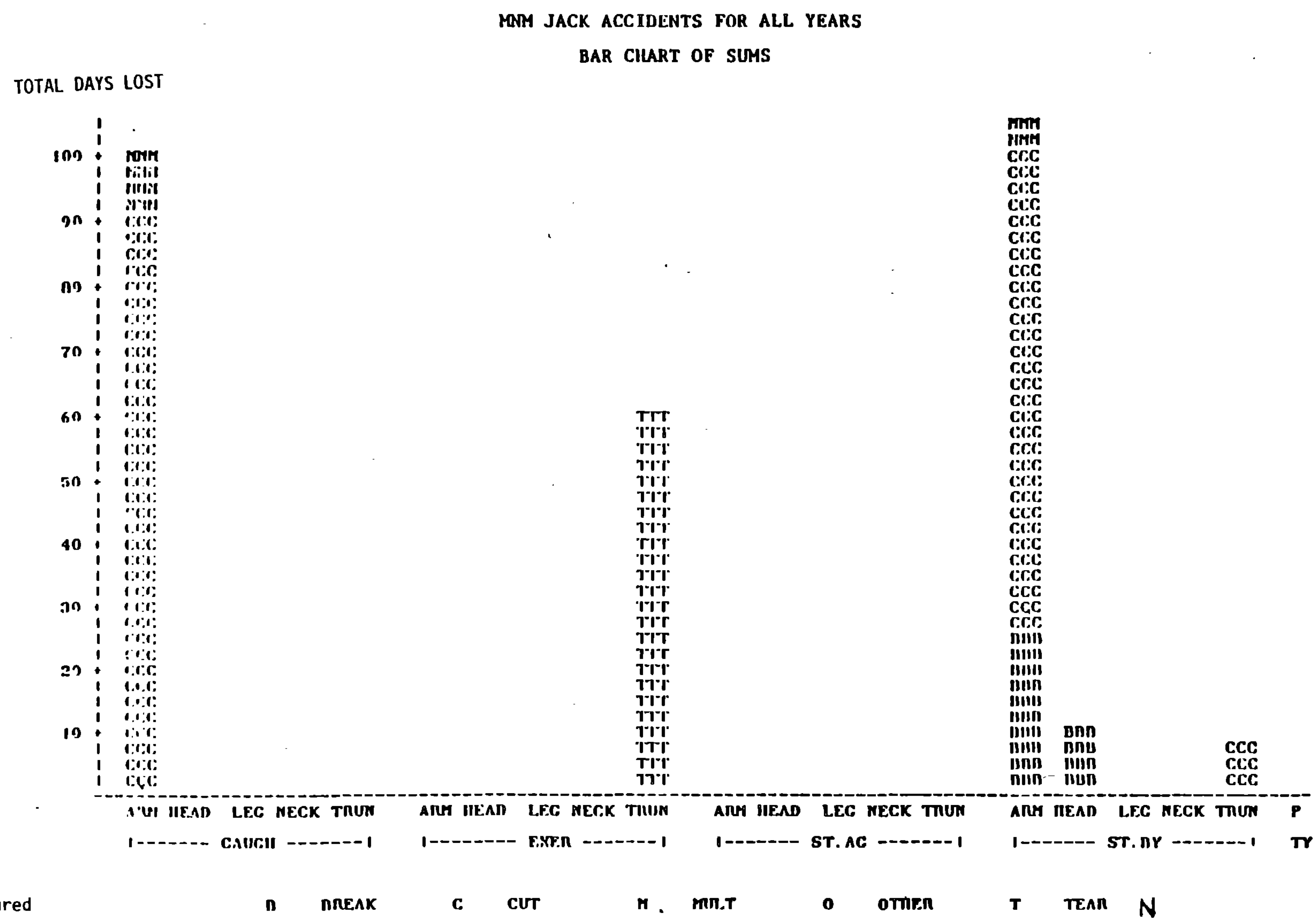
MNM JACK ACCIDENTS FOR ALL YEARS
PERCENTAGE BAR CHART



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-40: *Components of MNM jack accidents as a function of frequency.*



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

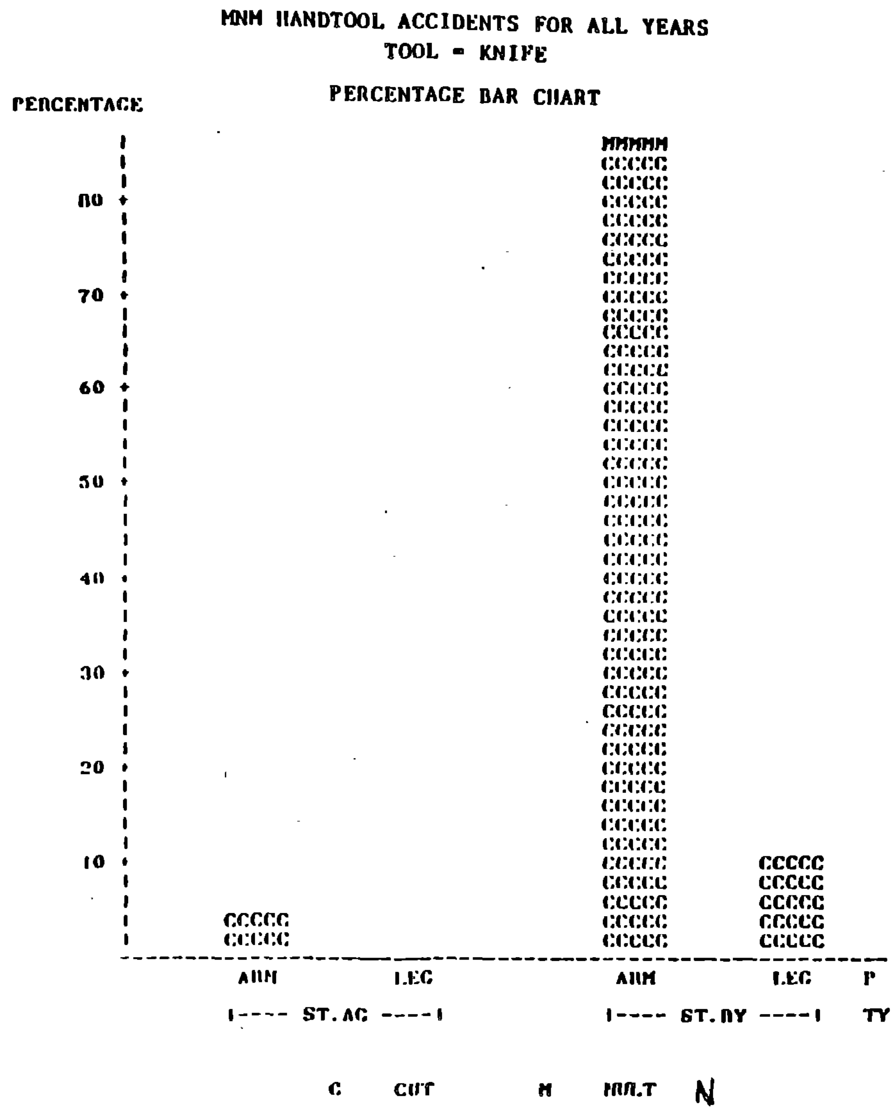
Figure 2-41: Components of MNM jack accidents as a function of lost days.

FIGURE 2-42: Tree diagram of jack accidents in MNM mines from 1978 to 1983 (N = 61).

```
CAUGHT  N= 17  (0.279)
TDL=  101  MEAN=  5.94
                         ARM    N= 17  (  1.000)
                         TDL=  101  MEAN=  5.94
                                        BREAK  N=  3  (0.176)  PR=0.0492   DAYS LOST=   0.33
                                        CUT    N= 11  (0.647)  PR=0.1803   DAYS LOST=   8.89
                                        MULT   N=  3  (0.176)  PR=0.0492   DAYS LOST=   3.67
EXERTION  N=  6  (0.098)
TDL=   59  MEAN=  9.83
                         ARM    N=  1  (  0.167)
                         TDL=    0  MEAN=  0.00
                                        TEAR   N=  1  (1.000)  PR=0.0164   DAYS LOST=   0.00
                         TRUNK N=  5  (0.833)
                         TDL=   69  MEAN= 11.80
                                        OTHER  N=  1  (0.200)  PR=0.0164   DAYS LOST=   0.00
                                        TEAR   N=  4  (0.800)  PR=0.0656   DAYS LOST=  14.75
STAG N=  1  (0.016)
TDL=    0  MEAN=  0.00
                         ARM    N=  1  (  1.000)
                         TDL=    0  MEAN=  0.00
                                        CUT    N=  1  (1.000)  PR=0.0164   DAYS LOST=   0.00
STBY N= 37  (0.607)
TDL=  123  MEAN=  3.32
                         ARM    N= 16  (  0.432)
                         TDL=  104  MEAN=  6.50
                                        BREAK  N=  6  (0.375)  PR=0.0984   DAYS LOST=   4.00
                                        CUT    N=  8  (0.500)  PR=0.1311   DAYS LOST=   9.50
                                        MULT   N=  2  (0.125)  PR=0.0328   DAYS LOST=   2.00
                         HEAD   N= 13  (0.351)
                         TDL=   10  MEAN=  0.77
                                        BREAK  N=  3  (0.231)  PR=0.0492   DAYS LOST=   3.00
                                        CUT    N= 10  (0.769)  PR=0.1639   DAYS LOST=   0.10
                         LEG    N=  4  (0.108)
                         TDL=    1  MEAN=  0.26
                                        CUT    N=  4  (1.000)  PR=0.0656   DAYS LOST=   0.25
                         NECK  N=  1  (0.027)
                         TDL=    0  MEAN=  0.00
                                        OTHER  N=  1  (1.000)  PR=0.0164   DAYS LOST=   0.00
                         TRUNK N=  3  (0.081)
                         TDL=    8  MEAN=  2.67
                                        CUT    N=  2  (0.667)  PR=0.0328   DAYS LOST=   4.00
                                        OTHER  N=  1  (0.333)  PR=0.0164   DAYS LOST=   0.00

     TOTAL  DAYS  LOST  =   283

     AVERAGE DAYS LOST  =   4.639
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)



KEY

P Part of body injured
TRUN Trunk injury
TY Type of injury
N Nature of injury
CAUGH Caught-type of accident
EXER Exertion-type accident
ST.AG Struck against
ST.BY Struck by

Figure 2-43: Components of MNM knife accidents as a function of frequency.

KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

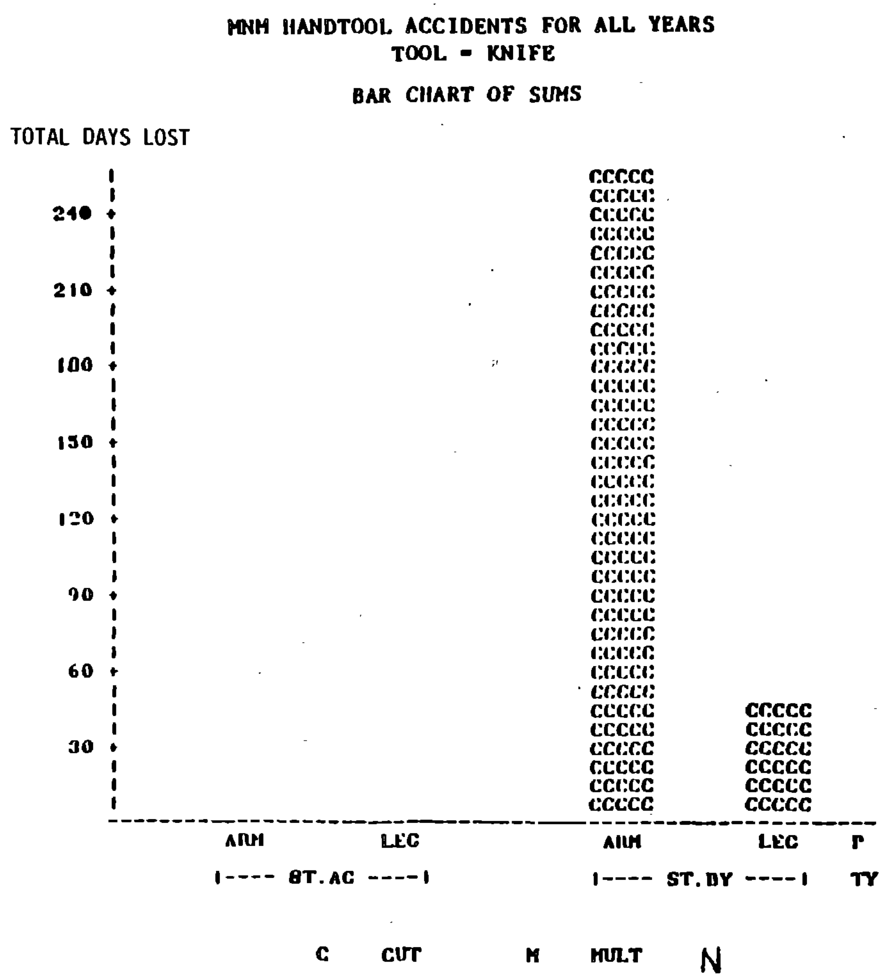


Figure 2-44: Components of MNM knife accidents as a function of days lost.

FIGURE 2-45: Tree diagram of knife accidents in MNM mines from 1978 to 1983 (N = 162).

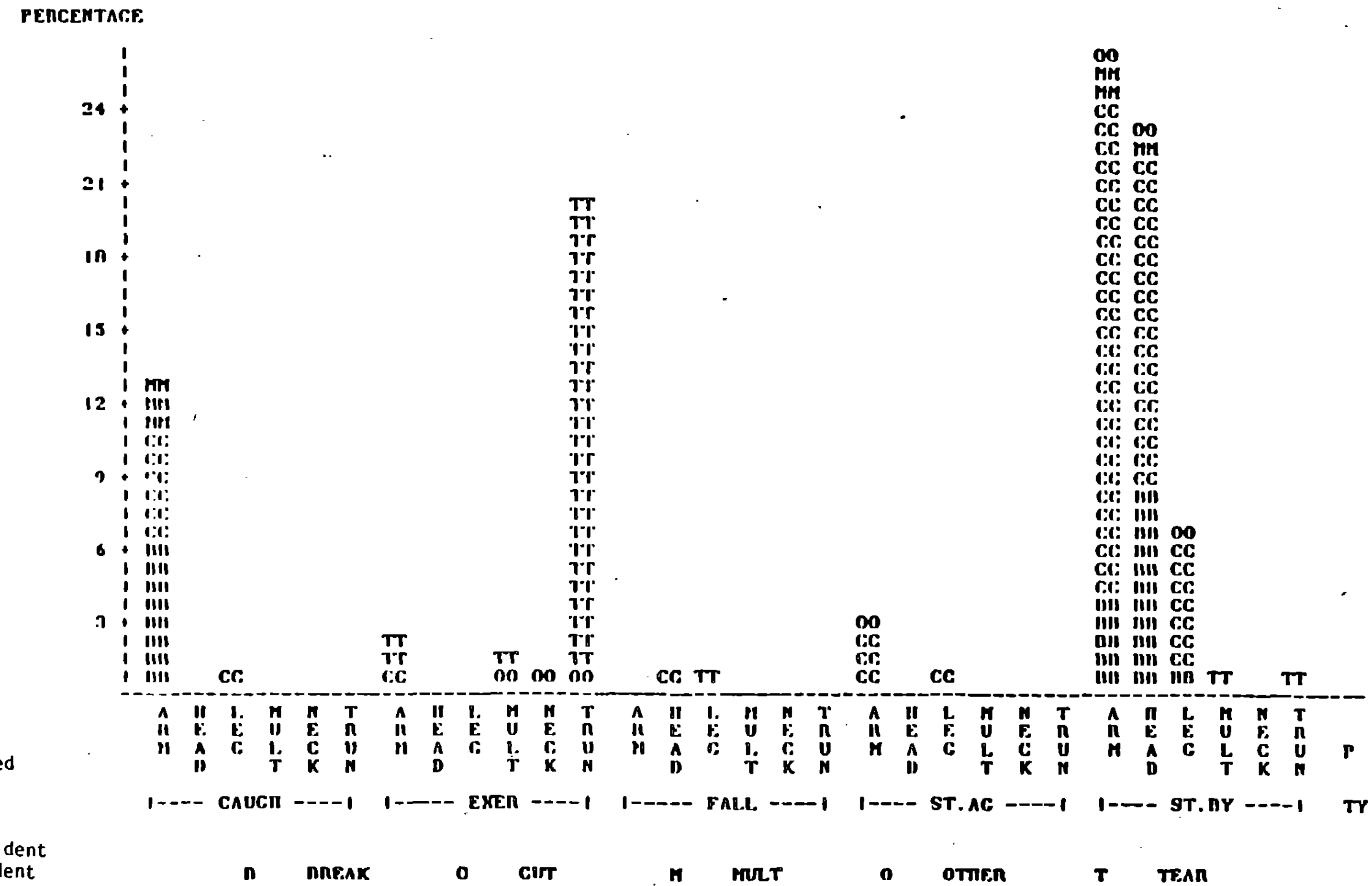
```
STAG N=   7  ( 0.043)
TDL=    0  MEAN= 0.00
                        ARM    N=   7  ( 1.000)
                        TDL=    0  MEAN= 0.00
                                          CUT     N=  7  (1.000)  PR= 0.0429     DAYS LOST=   0.00

STBV N= 155  ( 0.951)
TDL=  304  MEAN= 1.96
                        ARM    N= 138  ( 0.890)
                        TDL=  256  MEAN= 1.86
                                          CUT     N=136  (0.906)  PR= 0.0344     DAYS LOST=   1.88
                                          MULT    N=  2  (0.014)  PR= 0.0123     DAYS LOST=   0.00
                        LEG    N=  17  ( 0.110)
                        TDL=   48  MEAN= 2.82
                                          CUT     N= 17  (1.000)  PR= 0.1043     DAYS LOST=   2.82

         TOTAL  DAYS  LOST  =    304

         AVERAGE DAYS LOST  =   1.865
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

MNM HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = WRENCH

PERCENTAGE BAR CHART



KEY

P	Part of body injured
TRUN	Trunk injury
TY	Type of injury
N	Nature of injury
CAUGH	Caught-type of accident
EXER	Exertion-type accident
ST.AG	Struck against
ST.BY	Struck by

Figure 2-46: Components of MNM wrench accidents as a function of frequency.

MNM HANDTOOL ACCIDENTS FOR ALL YEARS
TOOL = WRENCH

BAR CHART OF SUMS

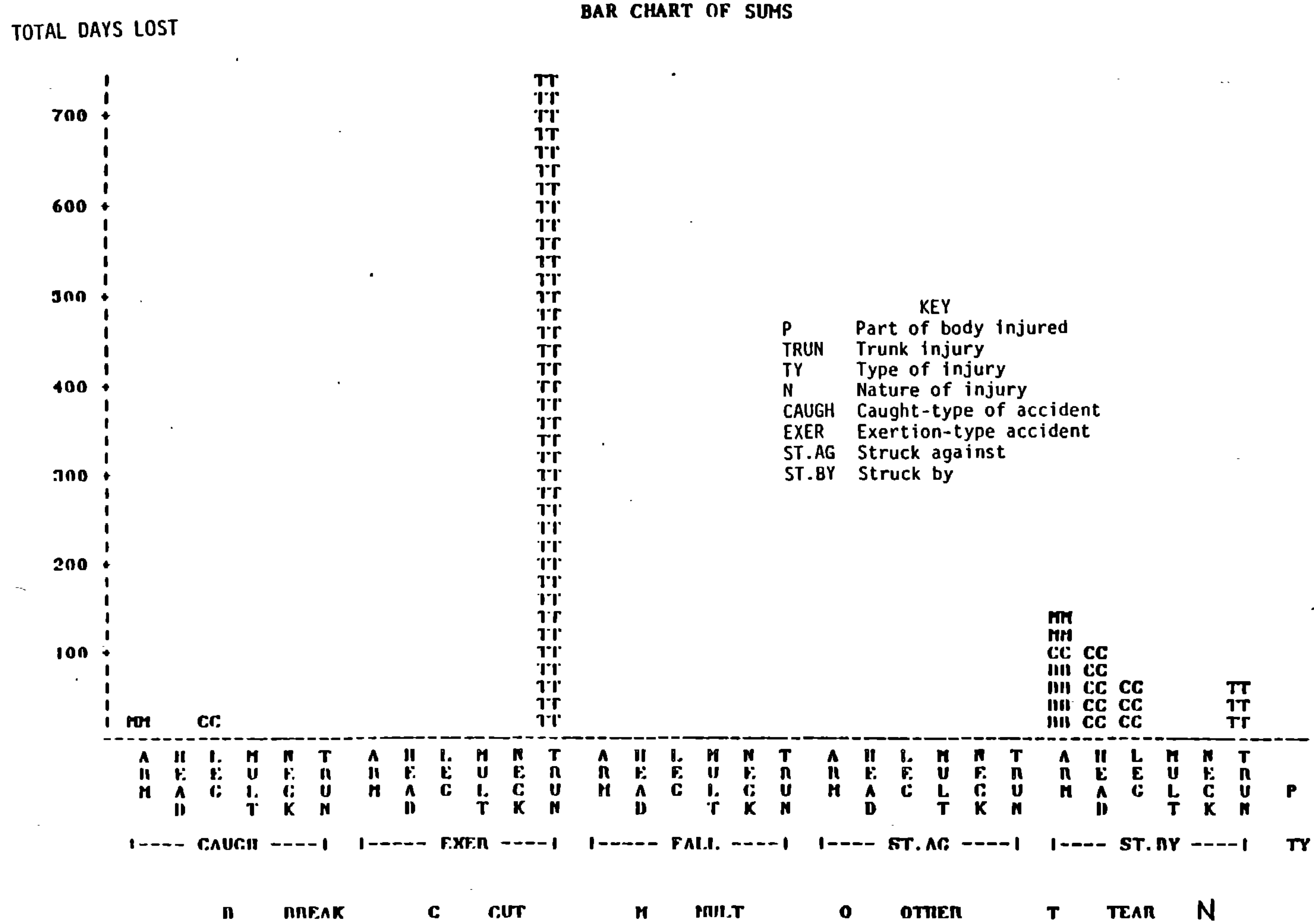


Figure 2-47: Components of MNM wrench accidents as a function of days lost.

FIGURE 2-48: Tree diagram of wrench accidents in MNM mines from 1978 to 1983 (N= 189).

```
CAUGHT  N=  24  ( 0.126)
TDL=   35  MEAN= 1.46
                          ARM     N=  23  ( 0.958)
                          TDL=    24  MEAN= 1.04
                                          BREAK   N= 11  (0.478)  PR= 0.0579    DAYS LOST=    0.00
                                          CUT     N=  8  (0.348)  PR= 0.0421    DAYS LOST=    1.13
                                          MULT    N=  4  (0.174)  PR= 0.0211    DAYS LOST=    3.75
                          LEG     N=   1  ( 0.042)
                          TDL=    11  MEAN=11.00
                                          CUT     N=  1  (1.000)  PR= 0.0053    DAYS LOST=   11.00

EXERTION  N=  47  ( 0.247)
TDL=  751  MEAN=15.98
                          ARM     N=   5  ( 0.106)
                          TDL=    14  MEAN= 2.80
                                          CUT     N=  2  (0.400)  PR= 0.0105    DAYS LOST=    3.50
                                          TEAR    N=  3  (0.600)  PR= 0.0158    DAYS LOST=    2.33
                          MULT    N=   3  ( 0.064)
                          TDL=     2  MEAN= 0.67
                                          OTHER   N=  1  (0.333)  PR= 0.0053    DAYS LOST=    0.00
                                          TEAR    N=  2  (0.667)  PR= 0.0105    DAYS LOST=    1.00
                          NECK  N=   1  ( 0.021)
                          TDL=     0  MEAN= 0.00
                                          OTHER   N=  1  (1.000)  PR= 0.0053    DAYS LOST=    0.00
                          TRUNK N=  38  ( 0.809)
                          TDL=  735  MEAN=19.34
                                          OTHER   N=  1  (0.026)  PR= 0.0053    DAYS LOST=    0.00
                                          TEAR    N= 37  (0.974)  PR= 0.1947    DAYS LOST=   19.86

FALL N=    2  ( 0.011)
TDL=     4  MEAN= 2.00
                          HEAD    N=   1  ( 0.500)
                          TDL=     0  MEAN= 0.00
                                          CUT     N=  1  (1.000)  PR= 0.0053    DAYS LOST=    0.00
                          LEG     N=   1  ( 0.500)
                          TDL=     4  MEAN= 4.00
                                          TEAR    N=  1  (1.000)  PR= 0.0053    DAYS LOST=    4.00

STAG N=    6  ( 0.032)
TDL=     8  MEAN= 1.33
                          ARM     N=   5  ( 0.833)
                          TDL=     8  MEAN= 1.60
                                          CUT     N=  4  (0.800)  PR= 0.0211    DAYS LOST=    1.25
                                          OTHER   N=  1  (0.200)  PR= 0.0053    DAYS LOST=    3.00
                          LEG     N=   1  ( 0.167)
                          TDL=     0  MEAN= 0.00
                                          CUT     N=  1  (1.000)  PR= 0.0053    DAYS LOST=    0.00

STBY N= 110  ( 0.579)
TDL=  372  MEAN= 3.38
                          ARM     N=  49  ( 0.445)
                          TDL=   139  MEAN= 2.84
                                          BREAK   N=  7  (0.143)  PR= 0.0368    DAYS LOST=   10.29
                                          CUT     N= 38  (0.776)  PR= 0.2000    DAYS LOST=    0.76
                                          MULT    N=  3  (0.061)  PR= 0.0158    DAYS LOST=   10.67
                                          OTHER   N=  1  (0.020)  PR= 0.0053    DAYS LOST=    6.00
                          HEAD    N=  45  ( 0.409)
                          TDL=   108  MEAN= 2.40
                                          BREAK   N= 16  (0.356)  PR= 0.0842    DAYS LOST=    0.00
                                          CUT     N= 25  (0.556)  PR= 0.1316    DAYS LOST=    4.24
                                          MULT    N=  2  (0.044)  PR= 0.0105    DAYS LOST=    0.00
                                          OTHER   N=  2  (0.044)  PR= 0.0105    DAYS LOST=    1.00
                          LEG     N=  13  ( 0.118)
                          TDL=    70  MEAN= 5.38
                                          BREAK   N=  1  (0.077)  PR= 0.0053    DAYS LOST=    0.00
                                          CUT     N= 10  (0.769)  PR= 0.0526    DAYS LOST=    6.60
```

```
                                  OTHER   N=  2  (0.154)  PR= 0.0185    DAYS LOST-   2.00
            MULT   N=   2  ( 0.010)
            TDL=    3  MEAN= 1.50
                                  TEAR    N=  2  (1.000)  PR= 0.0185    DAYS LOST-   1.50
            TRUNK N=   1  ( 0.005)
            TDL=   52  MEAN=52.00
                                  TEAR    N=  1  (1.000)  PR= 0.0053    DAYS LOST-  52.00

TOTAL  DAYS  LOST  -   1170

AVERAGE DAYS LOST  -   6.150
```

KEY

N	No. of lost-time accidents
TDL	Total days lost
MEAN	Avg days lost for this accident type or for this part of body
DAYS LOST	Avg days lost per incident for this nature of injury
( )	Probability that this segment will occur
PR	Probability that this entire sequence will occur
MULT	Multiple body parts injured or multiple natures of injury (e.g. breaks and cuts)
DUST	Dust in eye(s)

DISCUSSION

The analyses that have been reported thus far provided a microscopic view of the injury components for each tool. This discussion will draw collectively from the results of the previous analyses so that the problem can be viewed in a more macroscopic framework. The objective of this discussion is to identify those factors that have the potential to reduce injury risk by the greatest amount. This objective will be achieved by: (1) collectively assessing the risk associated with all tools, and (2) exploring the sequence of the injury components that are responsible for the risk, so the mechanism of injury can be identified.

Target Tools

The lost-time risk associated with the various hand tools is summarized in Table 2-3 for coal mining and Table 2-4 for metal-nonmetal mining. Table 2-3 shows that the lost-time risk associated with hand tool use in coal mining is primarily related to the scaling bar and the jack, and secondarily related to the pneumatic drill, hammer and axe, and pry bar. The use of the scaling bar and the jack contributes to more than half of all handtool-related lost work days.

An evaluation of tool injuries associated with metal and nonmetal mining presents a different picture. Jackleg drill accidents alone represent about 45% of all lost time. Scaling bar use is responsible for over 40% of lost work days. Thus, in this type of mining, jackleg drill use and scaling bar use represent nearly 85% of all lost-time risks associated with handtool injuries.

The risk of injury frequency was also evaluated as a function of mining type. Table 2-5 shows the accident frequency-risk ranking as a function of coal mining. Jacks, hammers, scaling bars, and knives are frequently associated with accidents, as well as having a high lost-day cost. Knife accidents appear as the third most common accident. However, knives were also shown to have a low lost-day risk. Therefore, even though knife accidents occur quite often they do not result in severe injuries.

The frequency risk associated with metal-nonmetal mining is shown in Table 2-6. This frequency-risk ranking agrees fairly well with the lost-time risk and indicates that the most serious hazards occur in jackleg drill and scaling bar use.

This analysis has helped define the focus of the study. Jackleg drill use and scaling bar use should be the primary focus of metal-nonmetal mining, whereas scaling bars and the other leverage instruments (pry bar and jack) should be the primary focus in coal mines. Additional focus is also warranted for the hammer and axe, and pneumatic drill use in coal mining.

Table 2-3. Lost-time risk associated with various tool use in coal mining (1978 to 1983).

	Tool	N	Total Lost Days	Average Days Per Accident	Pct of Total Lost Days of All Handtool Accidents
1.	Scaling bar	760	23,601	31.05	26.63%
2.	Jack	1,139	22,205	19.50	25.05%
3.	Pry bar	677	14,065	20.75	15.87%
4.	Hammer/Axe	1,104	11,105	10.05	12.53%
5.	Pneumatic drill	555	9,717	17.51	10.96%
6.	Wrench	430	5,688	13.20	6.42%
7.	Knife	840	2,258	2.69	2.55%

N = No. of injuries

Table 2-4. Lost-time risk associated with various tool use in metal and nonmetal mining (1978 to 1983).

	Tool	N	Total Lost Days	Avg Lost Days Per Accident	Pct of Total Lost Days of All Handtool Accidents
1.	Jackleg drill	1,913	18,048	9.43	44.11%
2.	Scaling bar	1,033	16,546	16.02	40.44%
3.	Pry bar	397	2,663	6.69	6.51%
4.	Hammer/Axe	405	1,902	4.69	4.65%
5.	Wrench	189	1,170	6.16	2.86%
6.	Knife	162	304	1.87	0.74%
7.	Jack	61	283	4.64	0.69%

N = No. of injuries

Table 2-5. Coal hand tools ranked by accident frequency

	Tool	Accidents	Pct
1.	Jack	1139	20.69
2.	Hammer and Axe	1104	20.05
3.	Knife	840	15.26
4.	Scaling Bar	760	13.81
5.	Bar	677	12.30
6.	Pneumatic Drill	555	10.08
7.	Wrench	430	7.81

Table 2-6. Metal-nonmetal handtools ranked by accident frequency

	Tool	Accidents	Pct
1.	Jackleg drill	1,913	45.99
2.	Scaling bar	1,033	24.83
3.	Hammer/Axe	405	9.74
4.	Pry bar	397	9.54
5.	Wrench	189	4.54
6.	Knife	162	3.89
7.	Jack	61	1.47

Coal Hand Tool Injuries

Table 2-7 lists the coal mining tools and the most severe injury type associated with them. This table rank orders the 10 most severe tool-injury type combinations for coal mining and indicates that over 80% of all lost-time injuries can be described by these 10 combinations. This analysis also shows that all of these accidents are due to struck-by or exertion injuries. Thus, the focus of the study will be further refined to these two accident types.

The relationship between all coal mining handtools, the types of accidents, and the part of body injured can be appreciated by examining the tree diagram shown in Figure 2-49. This figure further indicated that for the struck-by accidents, the arms, trunk, legs, and head are most often involved; similarly, exertion injuries always involve the trunk.

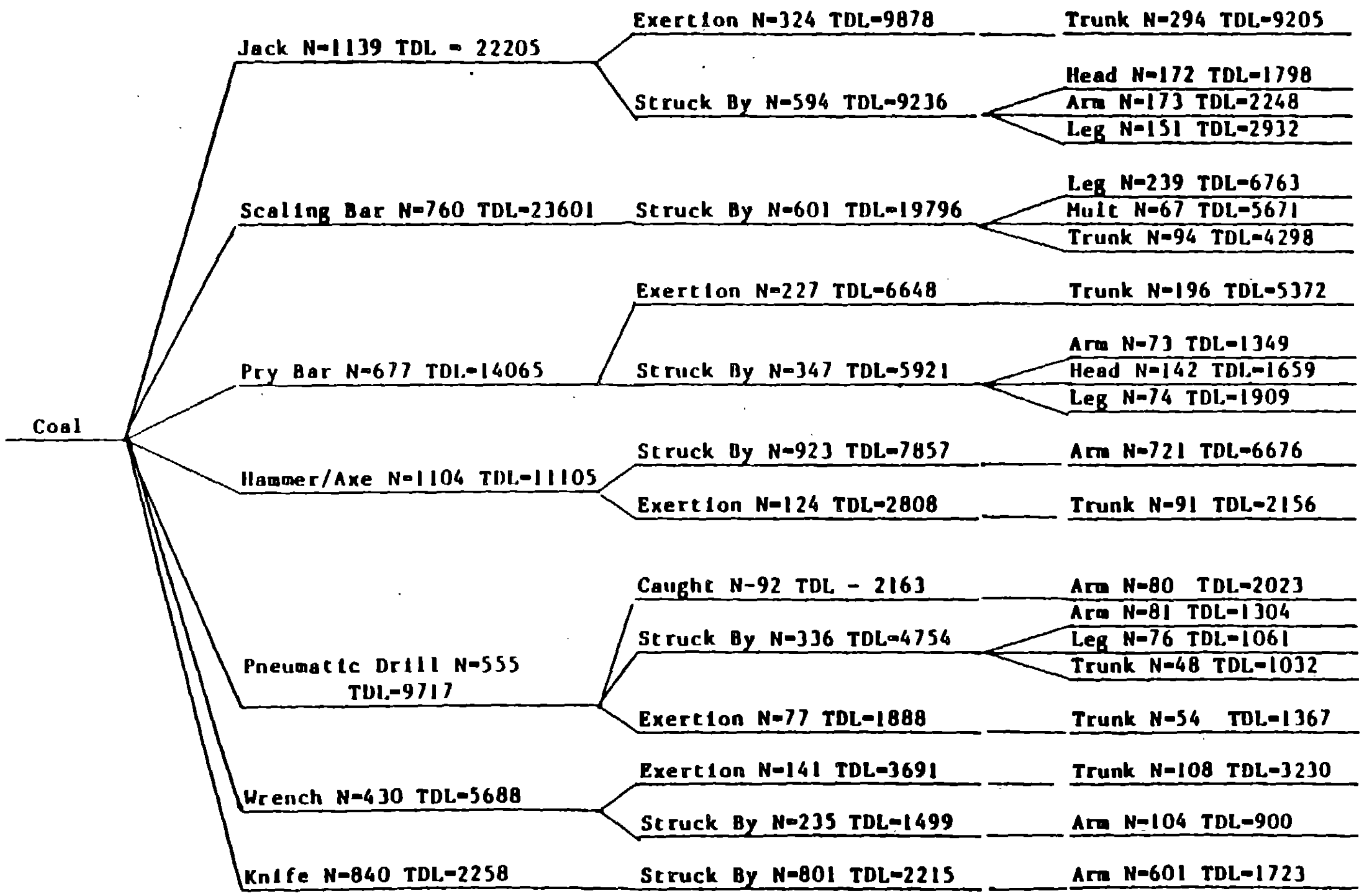
Table 2-7. Top ten coal accident types (1978 to 1983) as a function of lost days and percentage of all days lost.

	Tool DL	Tool	Type of Injury	N	Pct of all DL	Days Lost
1.	23,601	Scaling Bar	St-by	601	22.33	19,796
2.	22,205	Jack	Exert	324	11.14	9,878
3.	*	Jack	St-by	594	10.42	9,236
4.	11,105	Hammer/Axe	St-by	923	8.86	7,857
5.	14,065	Pry Bar	Exert	227	7.50	6,648
6.	*	Pry Bar	St-by	347	6.68	5,921
7.	9,717	Pneumatic Drill	St-by	336	5.36	4,754
8.	5,688	Wrench	Exert	141	4.16	3,691
9.	*	Hammer/Axe	Exert	124	3.17	2,808
10.	2,258	Knife	St-by	801	2.50	2,215
	88,639				82.12%	72,804

* No value is listed here; the days lost for a tool category is listed only once.

St-by = Struck-by
Exert = Exertion
N = No. of injuries
DL = Days lost

FIGURE 2-49: Tree diagram of the major injury components involved in coal mining handtool accidents.



KEY
N No. of injuries
TDL Total days lost

Metal-Nonmetal Hand Tool Injuries

The tool and injury-type relationships for metal-nonmetal mining (MNM) are shown in Table 2-8. This table rank orders the 10 most severe tool-injury type relationships. These 10 combinations represent nearly 90% of all handtool accidents and indicate a loss of over 36,000 days over the 6-year period. This table indicates that struck-by and exertion type injuries are involved in almost 87% of the incidents.

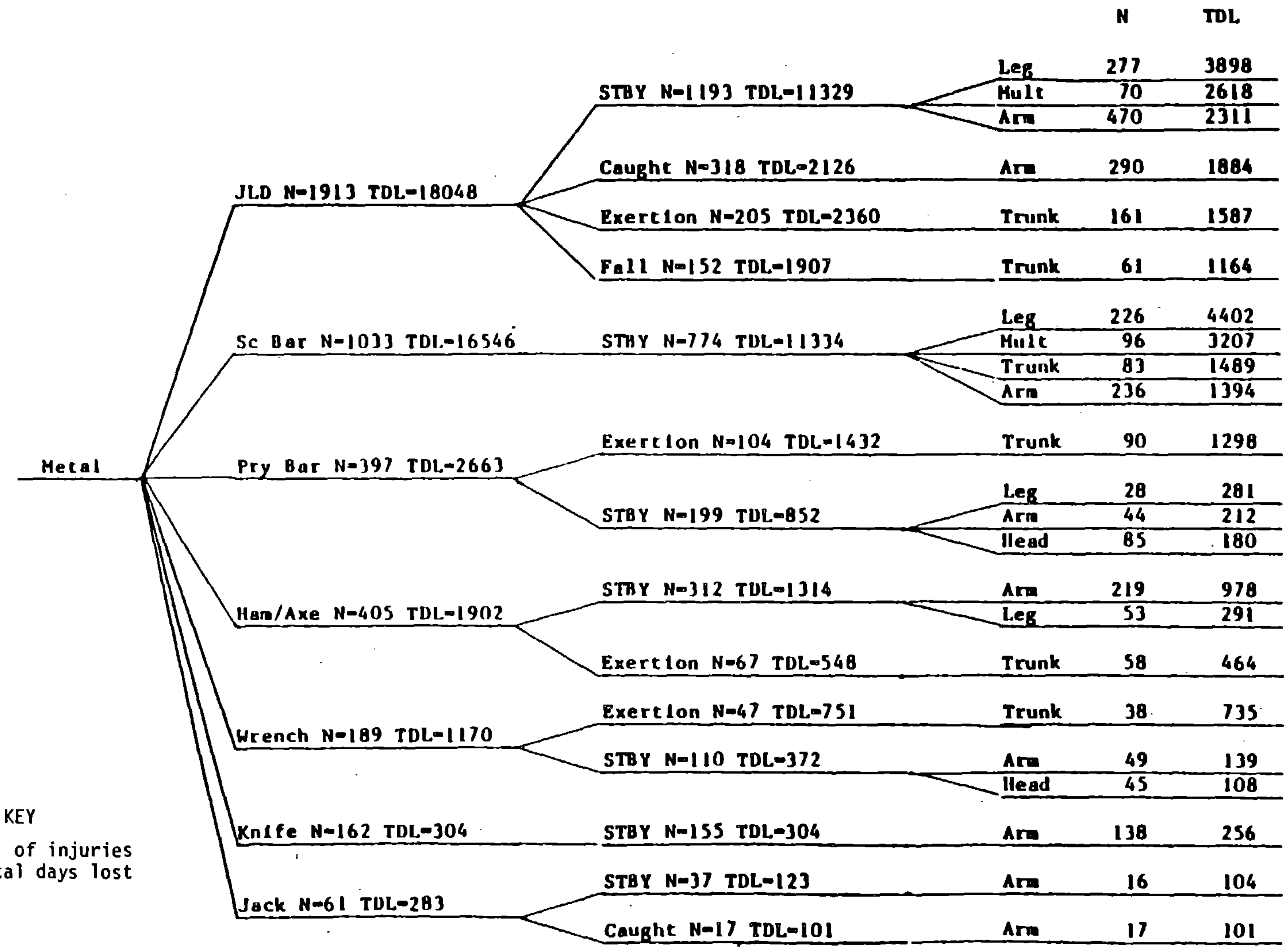
The overall conditional relationship between all tools, the type of accident, and the part of body affected can be appreciated by examining the tree diagram shown in Figure 2-50. This figure indicates that the most severe problems are associated with the jackleg drill and scaling bar. Struck-by accidents are the most costly types of injury that occur and these usually affect the legs or arms. Exertion injuries are also common when using these tools and always involve the trunk. The other major types of injury, which are common and unique to these tools, involve falls and caught-by injuries. These types of injuries usually affect the trunk or arm. Figure 2-50 provides a macroscopic view of the total MNM handtool problem. More detailed information regarding the aspects of each tool is available by referring to the conditional tree relationships presented in the Results section.

Table 2-8. Metal-nonmetal top ten accident types (1978 to 1983) as a function of lost days and percentage of all days lost.

	Tool DL	Tool	Type of Injury	N	Pct of all DL	Days Lost
1.	16,546	Scaling bar	St-by	774	27.70	11,334
2.	18,048	Jackleg drill	St-by	1,193	27.69	11,329
3.	*	Scaling bar	Fall	89	6.02	2,465
4.	*	Jackleg drill	Exert	205	5.77	2,360
5.	*	Jackleg drill	Caught	318	5.20	2,126
6.	*	Jackleg drill	Fall	152	4.66	1,907
7.	2,663	Pry bar	Exert	104	3.50	1,432
8.	*	Scaling bar	Exert	67	3.29	1,346
9.	1,902	Hammer/Axe	St-by	312	3.21	1,314
10.	*	Scaling bar	St-ag	55	2.63	1,078
	39,159				89.67%	36,691

* No value is listed here; the days lost for a tool category is listed only once. N: No. of injuries; DL: Days lost; St-by: Struck-by; Exert: Exertion; St-ag: Struck against.

FIGURE 2-50: Tree diagram of the major injury components involved in MNM mining handtool accidents.



KEY
N No. of injuries
TDL Total days lost

Common Tool-Component Relationships

The tools and sequences of component events that represented the greatest risks in underground mining (both coal and metal-nonmetal) were investigated. To accomplish this task, the macroscopic tree-branching diagrams, as well as the individual tree branches, for each tool were examined and the risk associated with each branch was rank ordered. This type of analysis has been considered as a function of lost days and frequency in Tables 2-9 and 2-10, respectively. These tables represent the 20 branches with the greatest risks of injury based on either the lost-day or frequency criteria for both coal and metal-nonmetal mining.

Table 2-9, which shows accidents as a function of lost days, indicates that among all tools in all types of mining, exertion accidents involving tears to the trunk and struck-by accidents resulting in breaks are responsible for the most lost days. On the other hand, table 2-10 shows that struck-by accidents involving cuts occur most frequently; this is followed by struck-by accidents causing breaks, and then exertion injuries involving tears of the trunk. Table 2-9 also indicates that approximately 87% of the most severe lost-time injuries occur in coal mining. However, if one examines accident frequency, the risk appears equally often in both types of mining. Hence, it appears that coal mining represents the greater risk (more lost days, yet similar frequency). These severity estimates, however, must be qualified by the amount of exposure time in each type of mining, a parameter that is very difficult to estimate.

Accident Scenarios

The information collected thus far regarding the components of handtool injuries was used to reconstruct the most common and most severe accidents, and assign causal relationships to these accidents. This process involved the creation of candidate scenarios for the accident component sequences of interest.

This process involved examining the sequence of component events and defining the various ways in which the injury might have occurred. The injury definition was achieved through the expert opinion of experienced mining engineers, personal data collection, review of MSHA narratives, and interviews and observations during the mine visits. For example, the third and sixth accident component sequences shown in table 2-9 may happen through the following sequence. A worker was scaling overhead when a rock slid down the scaling bar and hit the employee on the leg, thereby breaking it. Other scenarios for this same accident sequence are possible and will be developed.

Once the scenarios have been defined, the ergonomic factors that may play a part in the scenario will be assessed. For example, insufficient lighting or improper method of tool use may be responsible for such an accident. The scenario development process produced a specifically refined focus for Phase II. The possible sources of ergonomic problems that were considered with each scenario were presented in Table 2-2.

Table 2-9. Mixed coal and metal-nonmetal accident scenarios ranked by lost days for the period 1978 to 1983.

	Tool	Injury Type	N	Days Lost	Mine Type
1.	Jack	Exer-Trunk-Tear	277	8,258	C
2.	Pry bar	Exer-Trunk-Tear	183	5,168	C
3.	Scaling bar	Stby-Leg-Break	72	3,985	C
4.	Hammer/Axe	Stby-Arm-Break	304	3,775	C
5.	Scaling bar	Stby-Mult-Mult	33	3,492	C
6.	Scaling bar	Stby-Leg-Break	61	2,893	M
7.	Wrench	Exer-Trunk-Tear	99	2,817	C
8.	Jackleg drill	Stby-Leg-Break	56	2,331	M
9.	Hammer/Axe	Exer-Trunk-Tear	85	2,051	C
10.	Jack	Stby-Leg-Cut	110	1,975	C
11.	Hammer/Axe	Stby-Arm-Cut	316	1,965	C
12.	Scaling bar	Stby-Trunk-Break	23	1,849	C
13.	Scaling bar	Stby-Leg-Cut	127	1,778	C
14.	Knife	Stby-Arm-Cut	601	1,723	C
15.	Scaling bar	Stby-Mult-Mult	43	1,621	M
16.	Scaling bar	Stby-Mult-Break	7	1,610	C
17.	Jackleg drill	Exer-Trunk-Tear	148	1,466	M
18.	Jackleg drill	Stby-Mult-Mult	39	1,439	M
19.	Pneumatic drill	Caught-Arm-Break	28	1,410	C
20.	Pneumatic drill	Exer-Trunk-Tear	48	1,311	C
			2,660	52,917	

Exer = Exertion; Stby = Struck-by; Mult = Multiple; N = No. of injuries
C = Coal; M = Metal-nonmetal

Table 2-10. Mixed coal and metal-nonmetal accident scenarios ranked by accident frequency for the period 1978 to 1983.

	Tool	Injury Type	N	Days Lost	Mine Type
1.	Knife	Stby-Arm-Cut	601	1,723	C
2.	Jackleg drill	Stby-Arm-Cut	357	888	M
3.	Hammer/Axe	Stby-Arm-Cut	316	1,965	C
4.	Hammer/Axe	Stby-Arm-Break	304	3,775	C
5.	Jack	Exer-Trunk-Tear	277	8,258	C
6.	Knife	Stby-Leg-Cut	197	451	C
7.	Scaling bar	Stby-Arm-Cut	190	597	M
8.	Pry bar	Exer-Trunk-Tear	183	5,168	C
9.	Jackleg drill	Stby-Leg-Cut	175	998	M
10.	Jackleg drill	Caught-Arm-Cut	166	935	M
11.	Jackleg drill	Exer-Trunk-Tear	148	1,466	M
12.	Jackleg drill	Stby-Head-Cut	139	104	M
13.	Scaling bar	Stby-Leg-Cut	129	652	M
14.	Scaling bar	Stby-Leg-Cut	127	1,778	C
15.	Hammer/Axe	Stby-Arm-Cut	113	220	M
16.	Jack	Stby-Leg-Cut	110	1,975	C
17.	Jack	Stby-Head-Cut	104	464	C
18.	Wrench	Exer-Trunk-Tear	99	2,817	C
19.	Jack	Stby-Arm-Cut	88	956	C
20.	Pry bar	Exer-Trunk-Tear	86	1,274	M
21.	Hammer/Axe	Stby-Leg-Cut	86	1,274	C
			3,995	37,032	

Stby = Struck-by; Exer = Exertion; N = No. of injuries;
C = Coal; M = Metal-nonmetal.

CHAPTER 3: MINE VISITS

During the second phase of the project, seven underground mines were visited. Table 3-1 lists the reference name given to each mine, the main product mined, and the handtools observed. All of the handtools identified in the first phase of the project that significantly contributed to handtool accidents were sought out and observed during the visits. Each visit allowed for observations at multiple worksites involving a variety of tasks. These will be described in detail below.

Several types of data were collected during each visit. Tool use was videotaped using a low-light video system. Included on the image was a clock for the purposes of performing subsequent task analyses. Every effort was made to videotape variations in each tool's method of use, in addition to the variety of tasks for which the tools were used. The quality of the tapes improved during the later visits when supplemental lighting was available.

In addition to videotapes, still photos were taken during each observation period. Environmental data were collected with regards to temperature, humidity, air velocity at the face, and noise levels. Floor conditions were described and, where possible, the coefficient of friction was measured. Miners using the tools were also interviewed concerning their accident histories, and their interpretation of the accident scenarios identified during the epidemiological phase of the study.

Mine A

The first mine visited during this phase of the project was a small uranium mine. The hand tools observed included the jackleg drill, scaling bar, and pipe wrench. The miners were observed during the setup, rock-face drilling, blasting, scaling, and roof bolting operations.

During setup, miners had to carry to the worksite the tools they intended to use. For example, miners were observed carrying the jackleg drill by two distinctly different methods while performing this task. The rock face was drilled to a depth of 8 feet for the placement of explosive charges. This required drilling numerous holes at varying heights and orientations with the jackleg drill. After firing the explosive charges, scaling bars were used to bring down any loose material that had not fallen after the blast.

One feature of this visit included the observation of miners trying to free a stuck drill steel. Analysis of narrative reports (from the MSHA 7000-1 accident report) during the first phase of this project indicated that drill removal, and specifically, "hung" steel removal was a risky component of the drilling task, with regards to the incidence of low-back injury. Similarly, one miner was observed catching a falling jackleg drill. In studies investigating the mechanisms of back injury, this type of sudden-loading (or unexpected-loading) condition has been implicated as a likely condition preceding low back injury (Marras et al., 1987; Lavender et al., in press).

The drills observed weighed approximately 120 lbs. The sound level, measured 10 feet from the drill with the throttle wide open, was 118 dbA. At

TABLE 3-1

MINE VISITS

MINE	PRODUCT	ENVIRONMENTAL CONDITIONS	TOOLS OBSERVED
A	URANIUM	DRY	JACKLEG DRILL SCALING BAR WRENCH
B	URANIUM	WET	JACKLEG DRILL SCALING BAR PRY BAR
C	URANIUM	HOT/HUMID	JACKLEG DRILL SCALING BAR CHAIN SAW HAMMER
D	GOLD	DRY	JACKLEG DRILL PNEUMATIC WRENCH TORQUE WRENCH SCALING BAR
E	MOLYBDENUM	WATER ON HAULAGE LEVEL	SLEDGE HAMMERS JACKLEG DRILL SHOVELS SCALING BAR
F	COAL	DRY	SHOVELS PNEUMATIC DRILLS SCALING BAR SLEDGE HAMMER
G	COAL	DRY	JACKS WRENCH PRY BAR SCALING BAR

a distance of 20 feet from the tool, the sound level had dropped to 106 dbA. However, when two drills were in operation the sound level, at 20 feet away, was as high as 114 dbA.

The scaling bars used in Mine A were constructed from aluminum tubing with an outside diameter of 1 5/16 inches with a wall thickness of 3/8 inch. Two bars were observed; one was a 5 ft length of tubing and the other was 6 ft. Attached at the end of these bars were 7.5-inch curved steel tips.

Environmental data for this mine showed an underground temperature of 74° Fahrenheit. The wet bulb temperature was 66° F. Airflow in front of the ventilation pipe was 100 ft/min. At the worksite, air flow ranged between 50 and 100 ft/min. Floor conditions in this mine were dry but uneven, with numerous large rocks scattered about the worksite.

<u>Mine B</u>

The second mine was another uranium mine owned by the same company as Mine A. Handtools observed in this mine included the jackleg drill, scaling bar, and a prybar. The jackleg drill was observed again during face drilling and roof bolting tasks. The drill operator appeared to be more skilled than operators previously observed. Scaling was performed after the face had been blasted. The prybar was employed while trying to load a pump into the bucket of a front end loader. Floor conditions at the worksite observed in this mine were very wet. The miner was working in 3 to 4 inches of water during the face drilling phase. Following the blasting, the miner scaled the roof while standing on the pile of rock created by the blast.

Interviews with workers indicated problems from the vibration of the jackleg drill. These miners reported a "stabbing" sensation in their hands when they begin drilling for the day. The sensation is even more prevalent if they have been off the job a few days. One miner described the sensation as if his "funny bone" had been struck. These miners generally agreeded that their hands became cold quickly. Two miners described personal injuries that had occurred while on the job. One miner was struck by a falling rock that caused him to spin around and fracture an ankle. The other injury happened during roof bolting with a jackleg drill. The miner, in the process of trying to drive the roof bolt into the rock, pinched a finger.

<u>Mine C</u>

The third mine was a large uranium mine engaged in development operations. The jackleg drill, scaling bar, hammer, and a chainsaw were observed in this mine. The jackleg drill was being used to prepare a rock face for blasting, roof bolting, and for exploration. In uranium mines the quality of the ore is assessed with a Geiger counter. Before any ore is recovered, the site is tested for its ore quality. This is done by drilling test holes deep into the rock. The transducer component of the Geiger counter is then inserted into the rock to test for the direction in which they should mine next. Drilling these test holes is performed with a jackleg drill and accomplished by connecting several pieces of drill steel together.

The scaling observed in this mine was a demonstration of how the task is performed. We did not observe any miner using a scaling bar at any other time. At some worksites we inquired about them, which resulted in miners going to look for scaling bars. Two scaling bars were measured. The first was constructed from aluminum tubing 1.75 inches in diameter, with a wall thickness of .25 inch. The bar was 87 in long and weighed 5.5 lb. The steel tip was held in place with pins. The center of gravity of this bar was 36.5 inches from the tip. The second bar was fabricated from drill steel (7/8-in solid hexagonal steel section). It was 71 inches long and weighed 12.5 lb. The tip of this bar was forged into a duck-bill shape 1 7/8 in wide and angled at 20°. The balance point of this bar was 32.5 in from the tip.

Carpentry work was observed in this mine where an entry was being closed for ventilation control purposes. This task employed two miners using a chain saw and carpenter's hammers.

The temperature and humidity resulted in very warm, humid working conditions. The temperature ranged between 89° and 95° F, and the relative humidity ranged between 94% and 100%. To control the heat, ventilation was employed resulting in air velocities of up to 1600 ft/min. Each miner was given a gallon thermos container of ice water at the beginning of each shift. However, all miners indicated that this quantity was easily consumed during the course of a shift. The company uses no incentive system to boost production under these environmental conditions and only asks for an "honest day's work".

Sound level measurements at the drill sites were 118 dbA. At a distance of 50 ft from the face, the noise level was still at 105 dbA. Miners interviewed at this mine also indicated problems symptomatic of vibration, namely, hands that experience numbness, tingling at night, and coldness. One miner described his father, a rock driller for 30 years, as having hands with little temperature sensation and bumps at each joint.

Accidents described by these miners included severe finger injuries from rocks which either fell during drilling or slid down the scaling bar. One worker described a scaling bar accident that resulted in a friend's death.

Mine D

The fourth mine was a large gold mine. Two worksites were observed where jackleg drills were being used. Both sites were roof bolting operations. The first site was in the haulageway where some roof maintenance was taking place. The second site was in a shrinkage stope.

In this type of mining, a vein is followed, starting at the bottom, in an upward vertical direction. The roof of the stope is mined and the ore is drawn off at the bottom. Essentially the miners are working on top of the muck pile (the ore recently blasted from the roof). The ore is drawn off the bottom at a controlled rate to allow the miners to work effectively in the space on top of the pile. Following each blast, the roof is scaled and bolted before the next round of drilling begins.

The miners observed at this site were in the bolting phase of the mining cycle. This particular worksite was close to a generator so supplemental lighting was available. Therefore, this site provided the best opportunity for videotaping. Intermittent scaling was observed at this site as loose roof material was found. The holes for the roof bolts were drilled with jackleg drills. The bolts were then driven into the rock with a hand-held air wrench. A torque wrench was used to tighten each bolt to the proper setting.

Since these miners were working on the top of the muck pile, the footing conditions were poor. The miners were working on an uneven work surface with large pieces of rock scattered about the floor. Many of the smaller pieces of rock in this mine had very sharp edges. Thus, there was a high frequency of cuts reported by miners. The mine has now supplied each miner with a mesh sleeve to be worn while scaling and drilling to prevent these injuries (see Figure 3-1). However, neither of the drillers at the second worksite had their sleeves with them that day.

Mine E

The fifth visit was to a molybdenum mine. This mine used a caving technique for extracting their ore. This is when a layer of rock has been completely undercut and caves in on its own. The caving continues as the rock that has fallen is drawn off so that it no long supports the rock above. The caved rock is drawn off at the bottom through chutes, called finger raises, to the haulage level below.

On its way to the haulage level, the rock passes through what is called the "grizzly" level. Here the rock passes through a screen of steel bars that serves to restrict the size of the material reaching the haulage level. Material that is too large to pass through the grizzly must be broken into smaller pieces. This task is typically performed using sledge hammers. Since the rock that flows through the finger raises has to be initiated using bars approximately 5 feet long, the miners can control the flow of rock through the grizzly level. Miners performing this task also use shovels to keep the work platform clear of debris.

Observations at the grizzly level in Mine E included the use of sledge hammers, bars, and shovels in performing the tasks described above. Due to ore falling through the finger raises, working conditions in this section of the mine were exceptionally dusty. All miners wore respirators while they worked.

Another worksite was observed in a section of the mine where development was taking place. This allowed observations of the use of a jackleg drill and a scaling bar. The roof height was approximately 12 feet at this site. This required the scaling bar to be approximately 10 feet in length.

Floor conditions in the haulage level were wet and muddy. The grade on the haulage level was only 1%, which was inadequate to allow the water to drain toward the sump. This resulted in water at the haulage level that was up to 1 foot deep. The mud and water was occasionally causing derailments of

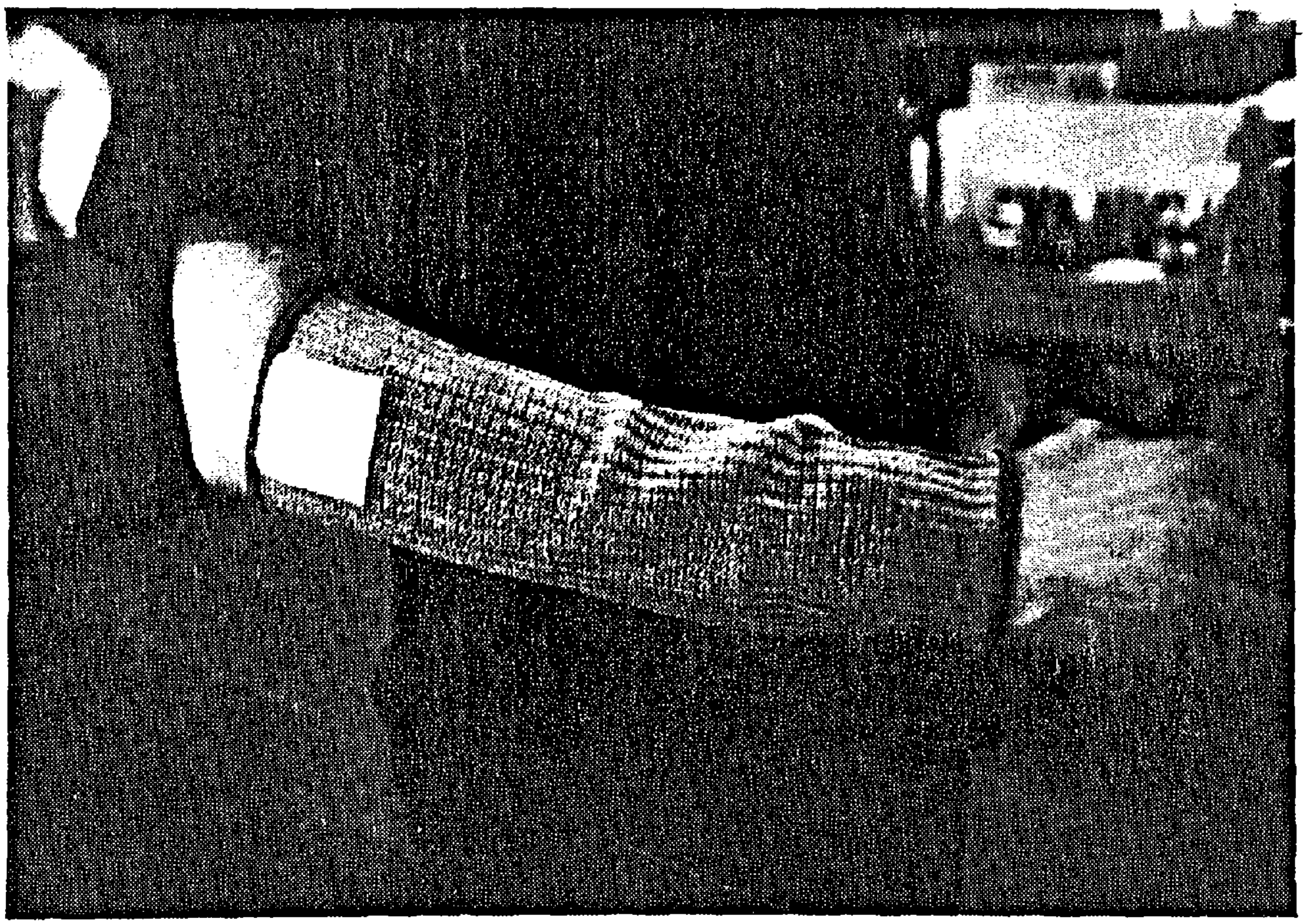


FIGURE 3–1: MESH SLEEVE SEEN AT MINE D

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the orecars. In addition, the water and mud required maintenance tasks at the haulage level to be performed under slippery conditions.

Mine F

The sixth mine visited was a small coal operation. They used the conventional mining technique of drilling and blasting. Thus, in this mine the use of hand tools at the face was more prevalent than at the larger coal mine that was visited next.

Miners in the smaller coal mine were observed using a Schroeder hydraulic hand-held coal drill. Figure 3-2 shows a miner using this tool and the body posture that was required while working in the 54-inch seam thickness. Although not shown in figure 3-2, the miner is standing in 3 to 4 inches of water.

The miners do little roof scaling in this mine since the top is smooth rock with no cracks. The operator of the roof bolting machine carried a scaling bar to be used when loose rib (the walls of the coal mine) conditions were encountered. A short demonstration of rib scaling was provided by this miner. The bar was 4 ft in length and made of steel.

Measurements taken on the hydraulic coal drill included the weight, peak driving force required to operate the drill, and the rotary torque at the handle. The drill weighed 60 lb and had a center of gravity approximately 8 inches in front of the motor casing (1.5 feet from the operator's end). Operation of the drill required up to 90 lbs of force to push the drill steel into the coal. The miner must also supply 35 lbs of force to overcome the 35 ft-lbs of torque present at the handles.

Other hand tools observed in this mine included a roof jack, sledge hammer, and shovel. The roof jacks, weighing 40 lbs each, were being removed after the completion of roof bolting. The sledge hammer (8 lbs) was used to break up pieces of coal that were too large to travel on the conveyor belt system. The shovel was used to clean up coal that the haulage vehicles did not get on the belt. This required the miner to shovel both in stooped and kneeling postures.

Mine G

The last mine visited was a large coal mine that afforded the opportunity to observe several hand tools. These included the scaling bar, roof jack, track jack, hammer, wrench, prybar, shovel, and spike maul.

The scaling bar was a 61-inch steel bar with a flanged tip. The bar was constructed from 1-inch diameter hex steel. Since the construction was uniform, the center of gravity of the 15-lb bar should be approximately 30.5 inches from either end. The scaling task was performed sporadically as loose material was spotted.

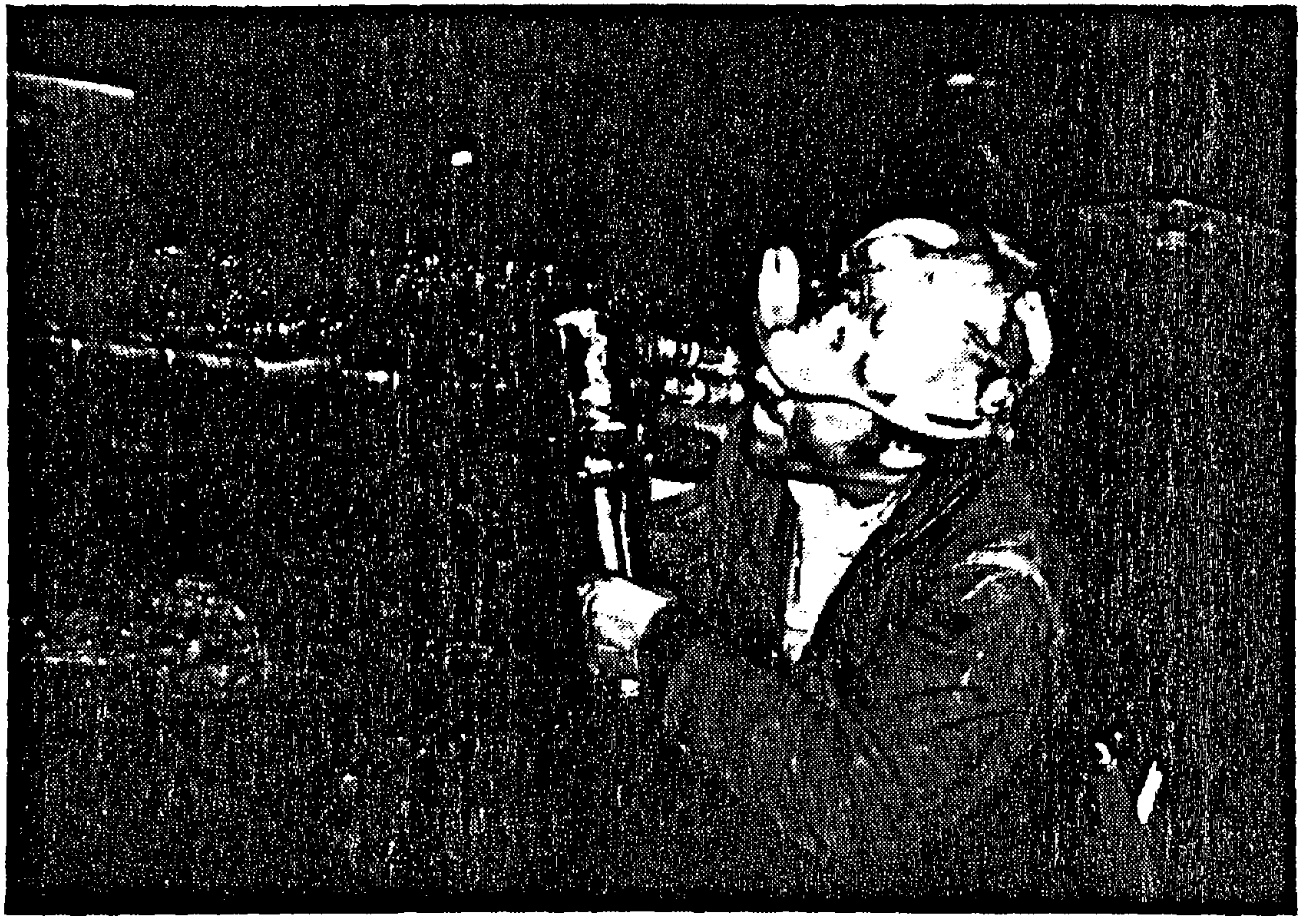


FIGURE 3–2: HYDRAULIC COAL DRILL IN USE AT MINE F

The roof jacks were set in the main haulageway where roof bolting was taking place. The jacks weighed 76 lbs and were handled, in our presence, by two miners. The jacks were set with a screw mechanism that was tightened by using a hammer. Smaller roof jacks were also observed being used in the 55-in roof conditions. These jacks weighed 53 lbs.

Track jacks were used in this mine for laying rail and putting derailed vehicles back on the tracks. Both of these operations were observed at this mine. Laying track required the use of jacks, prybars, wrenches, spike mauls, and shovels. The track is unloaded from a car one rail at a time. One end of the rail was attached to the car with a piece of rope and a shovel was pushed under the other end. The car was moved forward pushing the rail, which was maneuvered into position by a miner using the shovel. The final positioning of the rail was accomplished with the use of prybars and spike mauls.

The height of the rail was adjusted with a jack to insure the proper alignment of the connecting plates. These plates were bolted into position using an open end wrench. The peak force applied to the wrench to perform similar tasks has been measured at 200 lbs. The generation of force at this magnitude, while laying track in the low-seam conditions, likely supports the miner's claim that his "back is always sore on this job."

Good floor conditons, with little water and very little debris, were prevelant in the mine sections visited. The temperatures ranged between 61° and 65° F. The roof height was approximately 8 ft in the main haulageway. Everywhere else, the seam height was measured at 48 inches.

<u>Summary</u>

These seven mine visits provided the opportunity to observe all the handtools that were identified in the first phase of this project as contributors to the lost-time handtool injury problem. These tools were observed under normal working conditions so that the whole worker-tool-environment interaction could be studied. Special attention was paid to the method of tool use and variability seen from one miner to another. Tools such as the jackleg drill and the scaling bar, which are the top two contributors to handtool lost-time accidents, were observed as often as possible, and in as many different mines as possible. These data were used in the preparation of task analyses for each tool and were extremely useful in summarizing the ergonomic aspects of each tool identified in this study.

CHAPTER 4: TASK ANALYSES

INTRODUCTION

Video recordings of handtool use observed underground during the seven mine visits were used in the preparation of task analyses. These analyses are qualitative and quantitative descriptions of how the tools were used in the variety of methods observed underground. The objective of these analyses was to indicate the existing ergonomic problems in the tools and their observed methods of use.

METHOD

All videotapes used in the analysis had a clock value dubbed in the corner with 0.1 sec accuracy. The data from each tool was broken down according to the task the tool was being used to perform, and the basic elements of the task. Within each task, each element was timed and described qualitatively and quantitatively with regards to the body segments and tool position in space. These segments included trunk position, shoulder orientation, elbow angles, hand orientation, and leg positions. These angles (see Chaffin and Andersson, 1984) were determined by measuring the video images with a protractor. Where these measurements were not possible, the postures were imitated by an observer and the necessary measurements were collected.

Figure 4-1 shows an example of the data analysis for the scaling bar. As shown in the figure, roof height and floor conditions were also recorded where appropriate. The following analyses are broken down by tool and, where appropriate, by tasks.

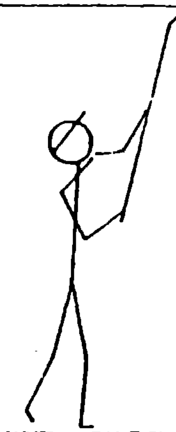
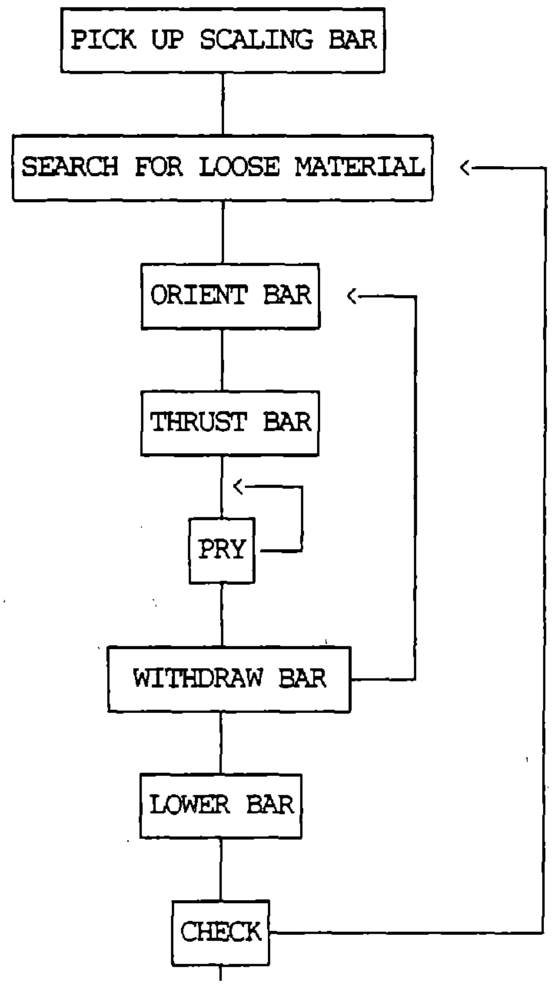
TASK ELEMENT	DURATION	FORCE ORIENTATION	ROOF HEIGHT	FLOOR	BAR ANGLE	BACK ANGLE	SHOULDER ABDUCTION	ELBOW ANGLE L & R	GROSS BODY ANGLE	HAND POSITION L & R	COMMENTS AND DIAGRAM
PRYING SUBJECT 1 AT MINE D	0.8 SEC	L ARM EXERTING FORCE UP THE BAR. R ARM PUSHING UP	9 FT.	UNEVEN W/ LARGE PIECES OF ROCK	75–90	0 – –5 ARCHING BACK	R: 20 – 80 L: 110–130	R: 100 – 120 L: 50 – 30	TWISTED TO RIGHT	R: 6" FROM END OF BAR L: 20" UP BAR FROM LEFT HAND	 NOTE: HEIGHT THAT THE END OF THE BAR MUST BE ELEVATED
PRYING – SUBJECT 2 AT MINE D	1.3 SEC	L ARM PUSHING UP	9 FT.	SLANTING DOWN SLIGHTLY W/ LARGE PIECES OF ROCK	60–20	STRAIGHT 0 – ARCHES BACK AS HE LIFTS BAR	R: 80 – 140 L: 90 – 110	R: 110 – 0 L: 90 – 110	TWISTED TO RIGHT	R: CUPPED AROUND END OF BAR L: DROPS OFF BAR AS BAR EXCEEDS REACH	 NOTE: ONE HANDED PRYING TECHNIQUE

FIGURE 4–1: EXAMPLE OF DATA ANALYSIS TECHNIQUE USED IN TASK ANALYSIS

SCALING BAR

The scaling bar was observed while roof and ribs were scaled in both high-and low-seam environments. The task can be broken into eight elements shown in the following diagram:



These eight elements will be described first for a typical case in high roof conditions (9 feet), followed by a discussion of the modifications observed in low-seam conditions.

Picking up the Bar

This task element was the first step in using the tool and required 0.9 seconds. Although not a strenuous task element, it did require 30 degrees of back flexion. The stress imposed in this element will be mostly influenced by the weight of the bar and the lifting posture.

Search for Loose Material

This task element was performed for varying periods of time up to 10 sec. A search is when miners scanned the roof or rib looking for cracks indicating loose material. Miners typically had only the light from their caplamp available. The detection of loose material was typically aided by sounding techniques. Sounding is tapping the bar against the rock until a hollow drum-like sound is heard. This sound is an indicator of loose material.

Miners, if not sounding, usually held the bar horizontal while scanning the mine roof. This resulted in the right shoulder abducted approximately 50°, the left hand held the bar near its center of gravity, and the right hand was near the end of the bar in its working position. The head was often tilted back as far as 30° while the roof was scanned.

Orient the Bar

This task element is the miner's preparation for thrusting the bar. It required about 0.5 seconds for the bar to be lifted from a roughly horizontal position to an upward orientation of 65°. The back was bent forward slightly (5°or so) and the left shoulder was abducted 35°. The right and left elbows were bent 90° and 110°, respectively. The grip of the right hand was not moved from its scan position, while the left grip slid closer to the right grip in preparation for the following action. The stance was usually with the feet about shoulder width apart for stability.

Thrusting

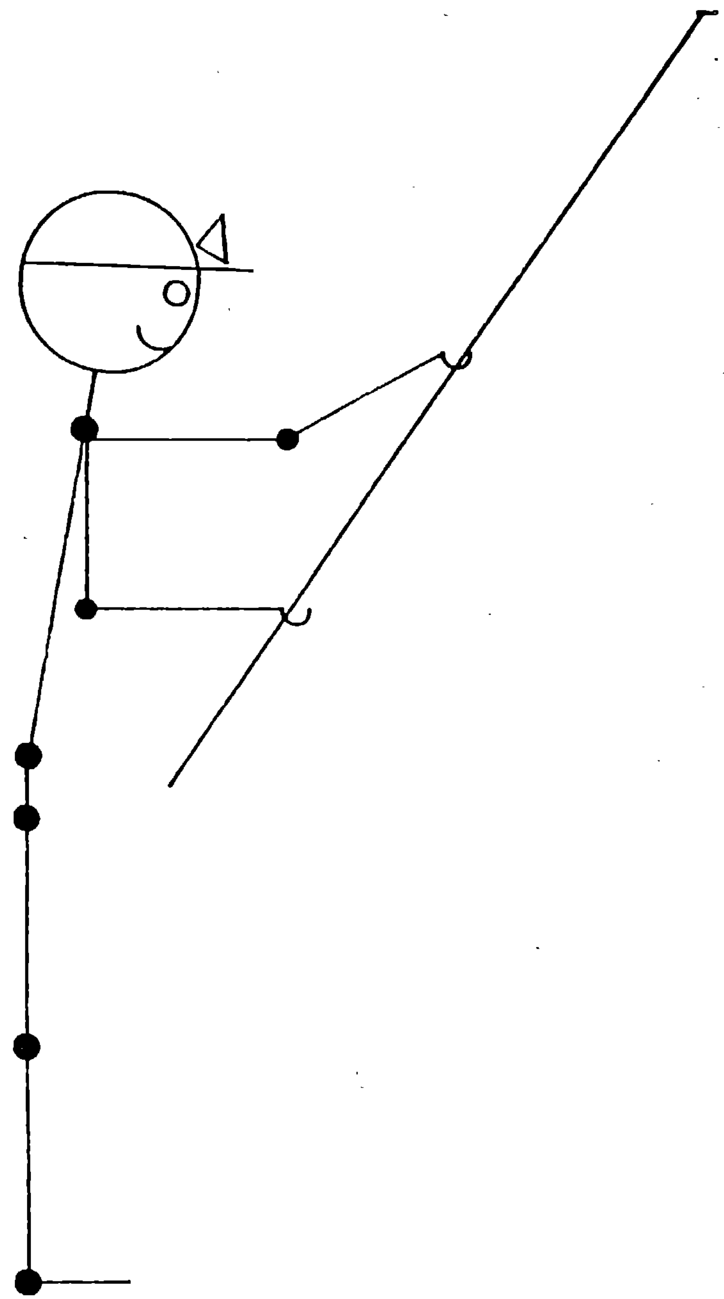
While this element was short in duration, roughly 0.1 to 0.2 sec, it probably required the most muscle force of the task elements described. During this element, the bar was accelerated toward the crack in the rock.

The postural changes observed during this task element were concentrated in the upper extremities. The bar was maintained at the 65° to 70° angle seen during the orienting phase. As shown in Figure 4-2, the back angle was increased to a posture with 10° of flexion. The right arm, which was observed to provide most of the power in the motion, was rotated inward at the shoulder, and was flexed 10° during the motion. The right elbow maintained 90° of flexion. The left arm played more of a guiding role with the shoulder going from 45° to 90° of abduction, and the left elbow extending from 110° to 70° of flexion. The position of the supinated left grip and the pronated right grip remained unchanged while the bar was extended. This resulted in ulnar deviation in both wrists as the bar was extended.

Prying

Once the tip of the bar has been jammed in the crack, the miner uses the scaling bar as a prybar and pries upward. Prying down puts the miner under the falling debris. While the prying motion described here only lasted 0.8 sec, it was, as indicated in the model above, often repeated until the loose material was removed.

During the motion, the end of the bar was lifted, resulting in a change in the bar angle between 10° and 30°. Also during the motion, the back was extended to an upright posture, the right shoulder was abducted from 10° to



SCALING:
TASK: THRUSTING
DURATION: 0.2 SEC
LOCATION: MINE D
ROOF HEIGHT: 2.74 m
BAR WEIGHT: 3.6 KG
BACK ANGLE: 10 DEG
BAR ANGLE: 55 DEG
SHOULDER FLEXION
L: 90 DEG / R: 10 DEG
ELBOW FLEXION
L: 25 DEG / R: 90 DEG
HAND POSITION
L: SUPINATED
R: PRONATED

FIGURE 4—2: THRUSTING THE SCALING BAR

60°, and the left shoulder remained abducted at 90° (see Figure 4-3). As the bar was raised, the right elbow was also extended from 90° to 130°, and the right wrist underwent further ulnar deviation. While most of the prying force was generated in the right shoulder, some of the force was coming from the back extensor muscles.

Variations observed in this task included cases where the bar was moved 35° to 40°. In one case, the final posture at the end of the prying motion had the miner completely extended with the bar at a 20° angle. The right shoulder was in 180° of forward flexion with the elbow straight. The left arm could not reach the bar but did catch it as it (and the loosened rock) fell. Other variations in prying showed substantial twisting to the right as the bar was lifted. In all variations of this task element, the left shoulder was routinely abducted in excess of 90° and the right shoulder in excess of 60°.

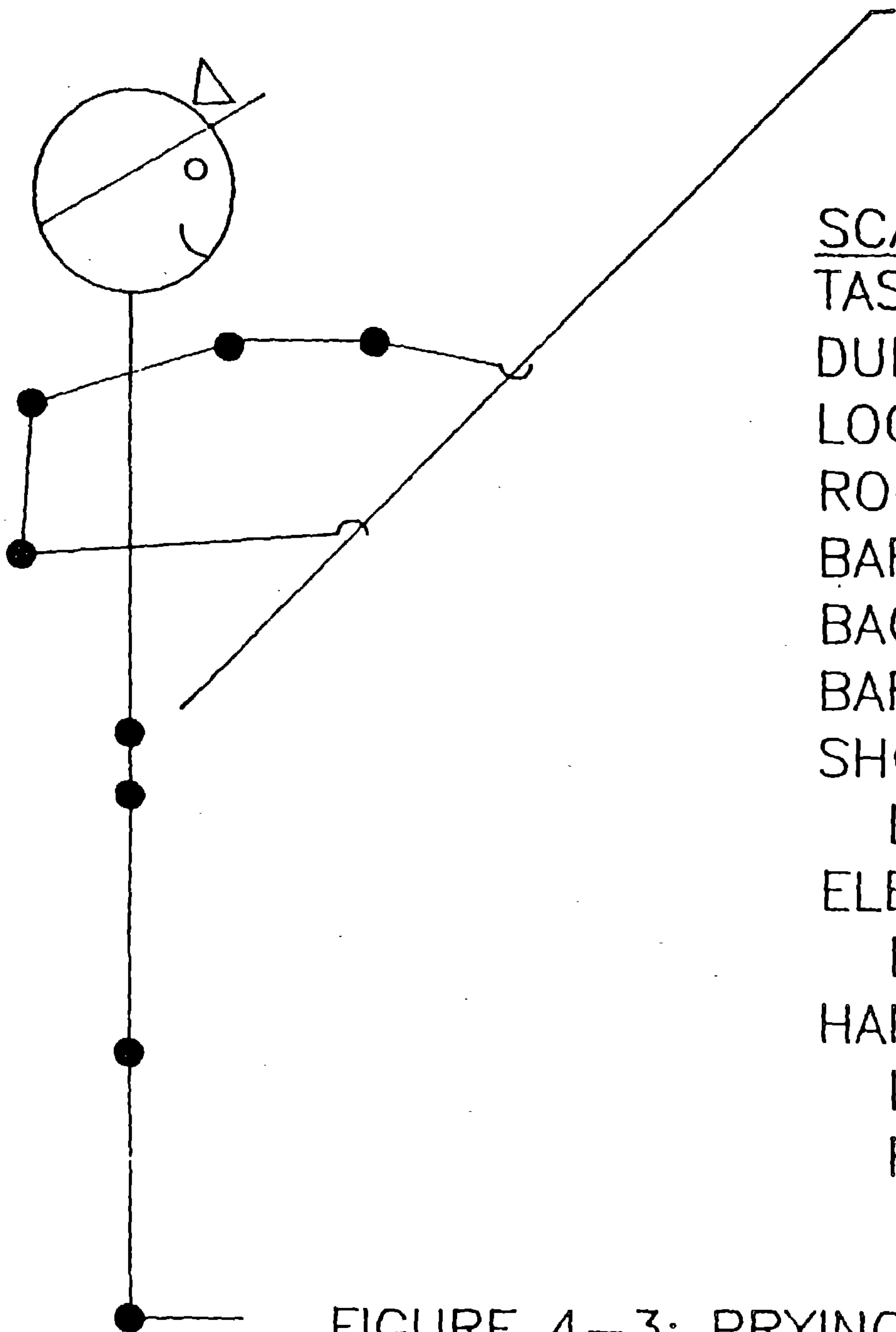
<u>Withdrawal of the Bar, Lowering the Bar, and the Check</u>

During these task elements the muscular loading was reduced. Often the withdrawal of the bar was followed by a reorienting and a repeat of the thrust and pry cycle. This was likely to be the case when the scaling was extensive, such as after blasting. When scaling was performed as part of worksite maintenance, the bar was often lowered back to a horizontal resting position while the work was checked and the whole cycle repeated. The check phase often included substantial twisting of the head and torso in order to move the caplamp without altering the foot placement. This was more frequently observed when the miners were scaling from on top of the muck pile where the footing conditions were poor (unstable).

<u>Variations seen in low-seam conditions</u>

In the 54-inch roof conditions, we observed both kneeling and stooped work postures while scaling. In the stooped posture, the miner's torso was bent forward 60°. This trunk angle required the miner's neck to be tilted back to allow adequate orientation of the caplamp. The miner was scaling the rib so the bar was essentially horizontal. The thrusting motion pushed the bar in front of the hips resulting in a substantial increase in torque about the L5/S1 junction. The prying component when the rib was scaled in the stooped posture is shown in Figure 4-4. Note that the prying was a side-to-side motion that was accompanied by a twist in the upper torso.

The kneeling posture required the miner's back to have 15° of flexion. The left shoulder, while abducted less than in high roof conditions, was abducted between 50° and 100° during the thrusting and prying elements. The upper body was also observed twisting during these elements. One observation of prying down was collected here. The miner pushed the bar down with both arms and followed the motion with a dip of the right shoulder. The bar angle went from 40° to 70°. When the miner was prying up, the bar went from 40° to horizontal, while approximately 12 inches in front of the torso. This resulted in extension of the back to 0° of flexion and the abduction of the left and right shoulders to 100° and 110°, respectively. Both elbows were at 70° of flexion. At the top of the motion, the left wrist, with a supinated grip, was completely extended and the right wrist, with a pronated grip, was completely flexed.



SCALING:
TASK: PRYING
DURATION: 0.8 SEC
LOCATION: MINE D
ROOF HEIGHT: 2.74 m
BAR WEIGHT: 3.6 kg
BACK ANGLE: 0 DEG
BAR ANGLE: 50 DEG
SHOULDER ABDUCTION
L: 90 DEG/ R: 10–60 DEG
ELBOW EXTENSION
L: 90 DEG / R: 90–130 DEG
HAND POSITION
L: SUPINATED
R: PRONATED

FIGURE 4–3: PRYING HIGH ROOF CONDITIONS

SCALING:
TASK: PRYING
DURATION: 9 SEC
LOCATION: MINE F
ROOF HEIGHT: 1.37 m
BAR WEIGHT: 3.6 kg
BACK ANGLE: 60 DEG
BAR ANGLE: −10 DEG
SHOULDER ABDUCTION
L & R: 25 DEG
SHOULDER FLEXION
L & R: 20 DEG
ELBOW FLEXION
L & R: 80 DEG
HAND POSITION
L: PRONATED
R: PRONATED

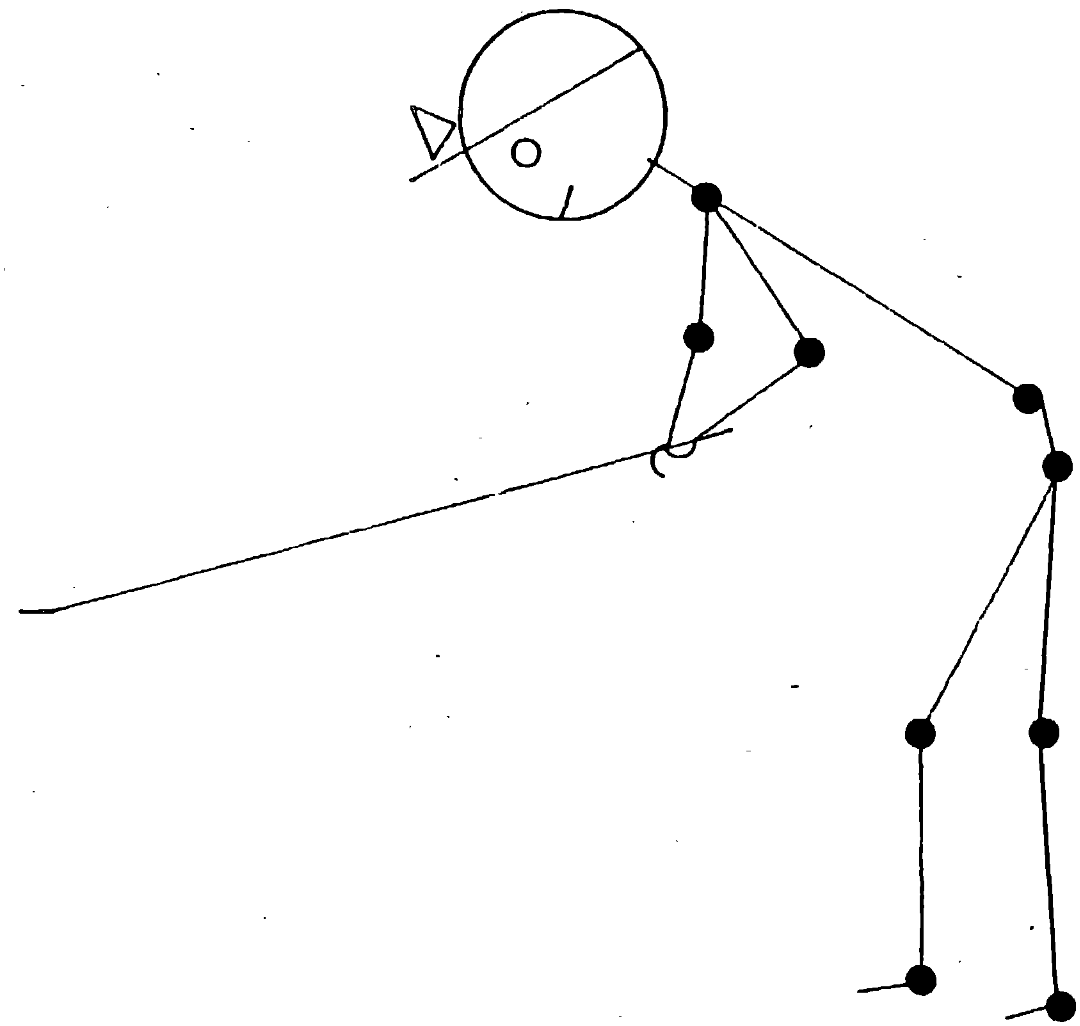
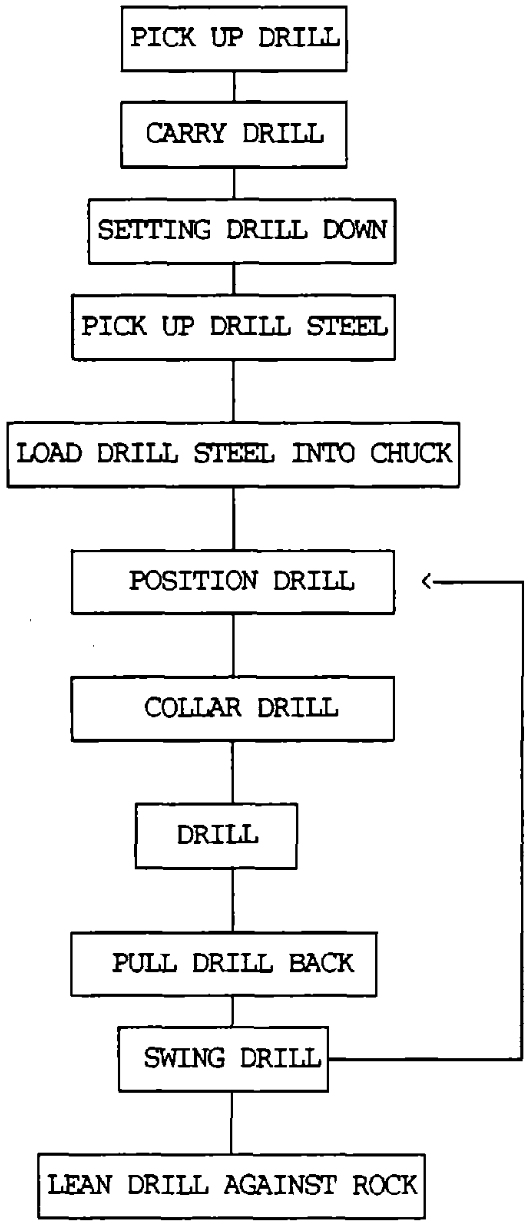


FIGURE 4–4: PRYING RIB IN LOW SEAM CONDITIONS

JACKLEG DRILL

The jackleg drill was observed during routine drilling and roof bolting. The task analysis for this tool will focus on the former since roof bolting is just the special case where the holes are close to vertical. The drilling task consists of the 11 elements shown below:



Picking up the jackleg drill

The observed work cycles began with the drill either laying on the ground or leaning against the mine wall. From either initial position, the lifting technique was the same. Lifting from the ground, however, was more strenuous. With the drill initially laying on the ground, the miner worked from a stooped posture, with knees bent at approximately 30°. The 120 lb drill was lifted by the operator using the leg control handle and the drill chuck. As the drill body was raised, more and more weight was shifted to the drill leg. Once the body was directly above the leg, the drill was ready to be lifted and carried. This task element placed extreme loads on the lumbar spine for a duration of approximately 5 seconds. The trunk was bent forward 90° at the beginning of the lift. The torso was also twisted to the right as the drill leg neared a vertical orientation.

<u>Carrying the Jackleg Drill</u>

Two methods of carrying the drill were observed underground. In the first method, the drill body was cradled in the left arm and the "D" handle held in the right hand. This method required the miner to extend his back approximately 10°. The left arm supported most of the weight causing the torso to have some lateral flexion to the right. As shown in Figure 4-5, the drill casing was cradled by the left arm and the right arm was completely extended to reach the"D" handle. With the drill carried in front, the miner's view of the walking surface was obstructed. This would likely lead to frequent stumbles and possible falls.

In the second method, the drill was carried on the shoulder. Although the first method was observed more frequently, the second method was preferred for longer carries which were less common. Carrying the drill on the shoulder required the miner to walk with 20° of flexion in the torso. Essentially, the drill was rested on the shoulder and only the right arm was used to hold it there. With this much weight on only one shoulder, substantial shear forces would be expected on the L5/S1 intervertebral disk.

<u>Setting the drill down after carrying</u>

When the miner carried the drill in front, the leg was easily lowered to the ground and the drill weight quickly shifted to it. However, when the drill was carried on the shoulder, the miner had to bend forward another 30° (now 50° of flexion) to lower the leg to the ground.

<u>Pick up drill steel</u>

Once the drill was resting on the air leg, the miner needed to insert the drill steel. The steel, which was usually laying on the ground, had to be picked up with one hand, while the drill was balanced with the other hand. This resulted in the miner holding the drill with the right hand, bending forward 90 degrees with the torso, twisting to the right (further lowering the left shoulder), and extending his left hand to pick up the drill steel (see Figure 4-6). This action took 3 seconds to complete since the motion was relatively slow. During this period, the miner was in a precarious posture if the drill began to fall or his footing gave way.

<u>Load drill steel into chuck</u>

Usually, the steel was picked up near its center of gravity. Since one hand was supporting the drill, the steel must be aligned with the chuck using only the remaining hand. This was accomplished by repeatedly throwing the

JACKLEG DRILL:
TASK: CARRYING DRILL
DURATION: VARIES
LOCATION: MINE A
DRILL WEIGHT: 120 lb.
BACK ANGLE: −10 DEG
SHOULDER ABDUCTION
  L: 45 DEG / R: 35 DEG
ELBOW FLEXION
  L: 90 DEG / R: 0 DEG
HAND POSITION
  L: SUPINATED
  R: PRONATED

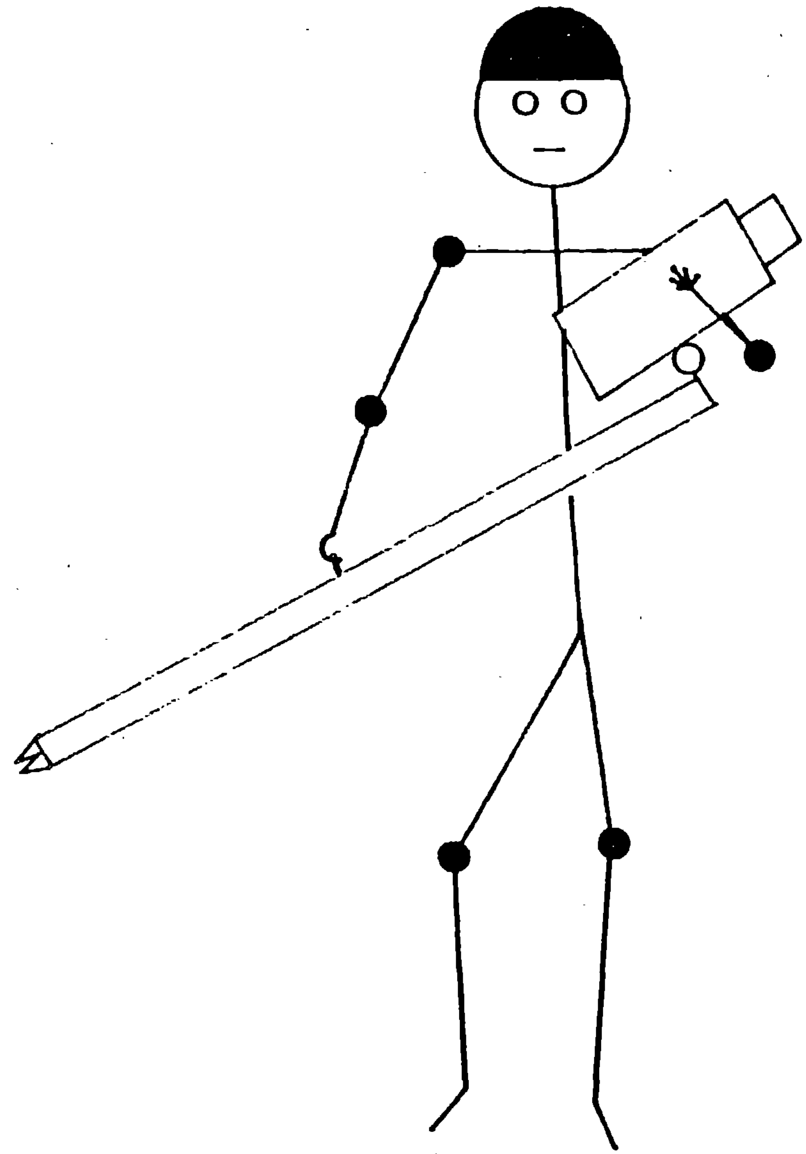


FIGURE 4—5: CARRYING THE JACKLEG DRILL

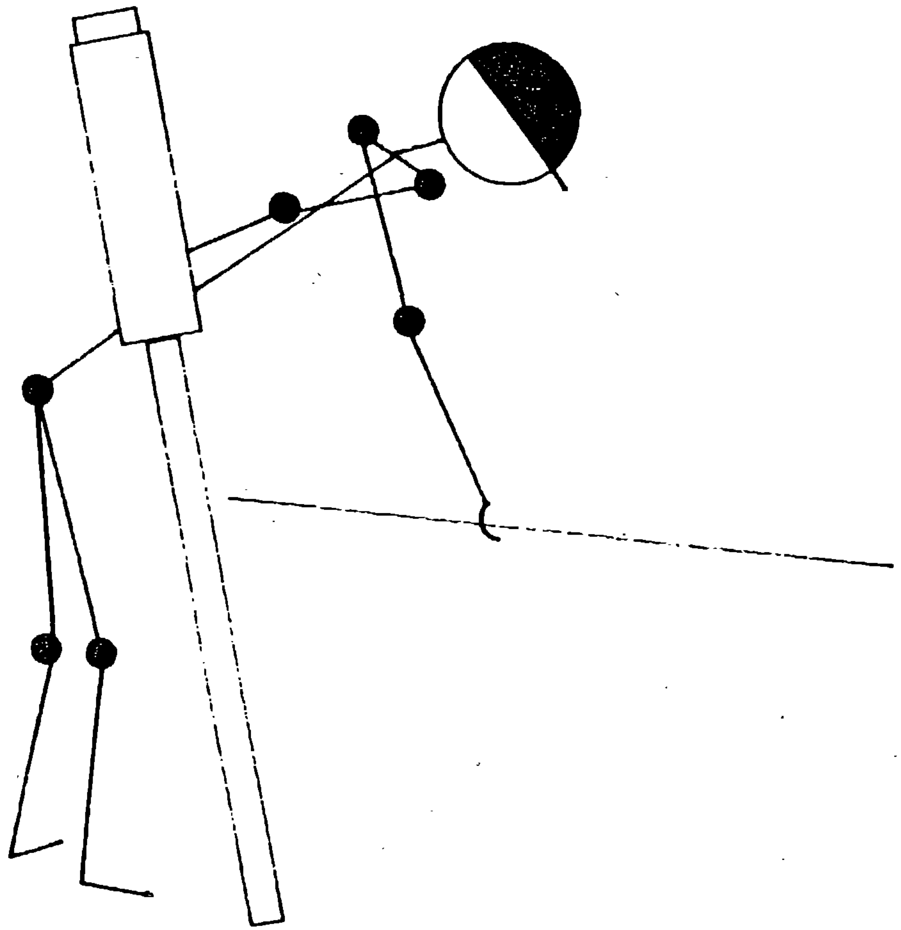


FIGURE 4—6: PICKING UP DRILL STEEL

steel upwards in a vertical orientation and catching it closer to the end that was to be inserted into the chuck. This procedure, should the steel not remain vertical, places excessive torque on the wrist. The further from a vertical orientation, the greater the torque. The steel was likely to stray from its vertical orientation either by striking the mine roof, or from a bad throw or possibly a bad catch. In either case, poor lighting could be a factor.

<u>Positioning Drill</u>

In this task element, the miner wrestles the drill into position so the hole can be started. The miner's task is to counterbalance the forward torque due to the weight of the drill. As shown in Figure 4-7, the miner was observed leaning back approximately 10°, with the upper torso twisted to the right. This posture allowed the left arm, which was extended 70°, to reach in front of the drill chuck with a supinated grip and still be near the optimal joint angle for muscle force. There appeared to be excessive muscular force developed in the posterior muscle groups.

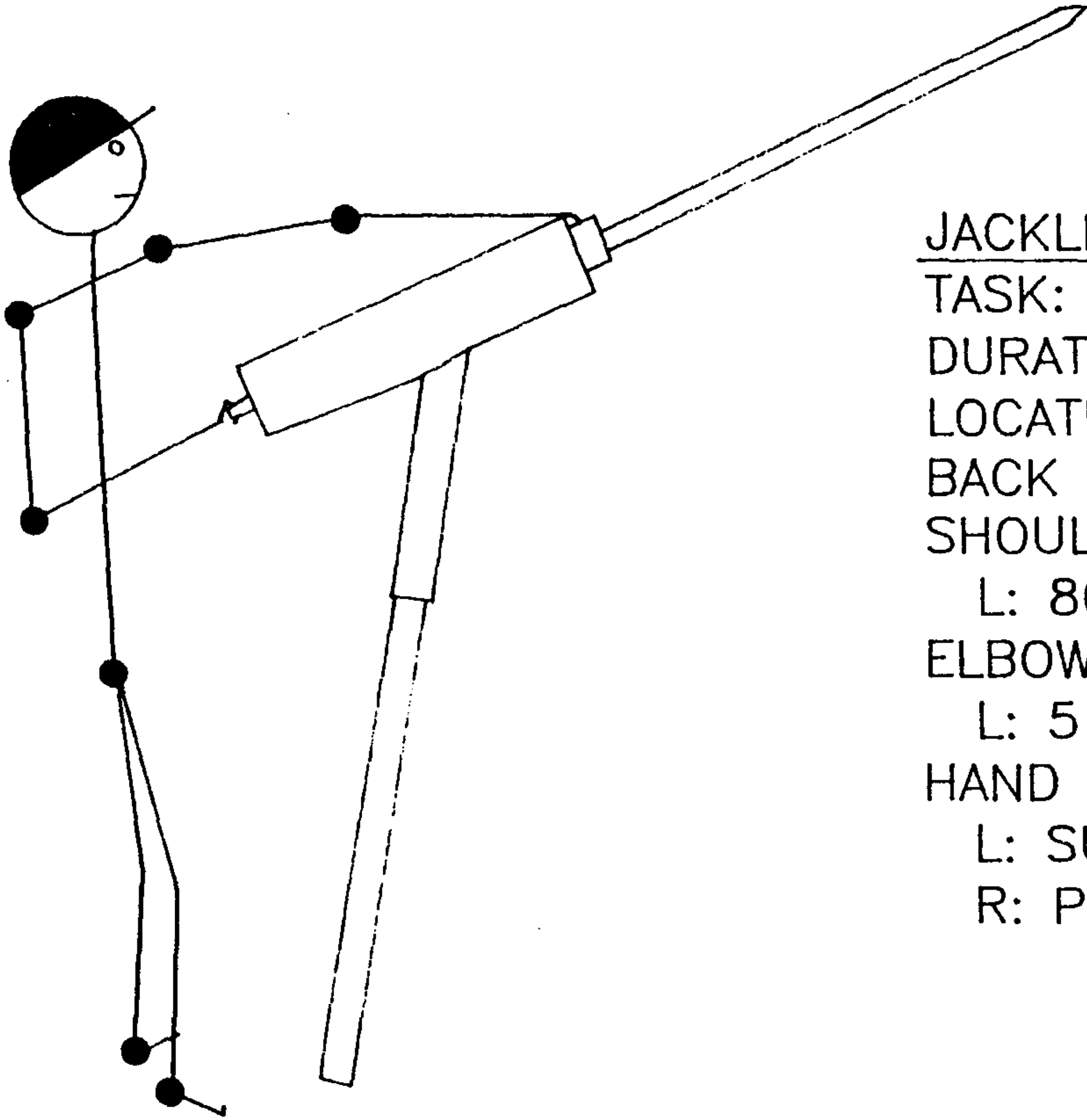
<u>Collaring the Drill</u>

Once the drill was positioned, the miner turned the throttle on low to start drilling the hole in the rock. Once the drill bit had started cutting, the throttle was turned wide open and the miner no longer supported much of the drill's weight. The change in the throttle marked the end of collaring and the beginning of drilling. The duration of this task varied, depending on the composition of the rock and the availability of irregularities in the rock surface to let the drill bit start cutting the rock. The collaring durations most frequently recorded in our observations ranged between 8 and 12 sec.

During collaring, the miner was forced to remain in a static work posture supporting much of the drill's weight. One observed posture, where the miner was standing just behind the drill, placed the back in 10° of flexion, and caused the back to be twisted to the right (see Figure 4-8). Figure 4-9 shows another collaring posture frequently used where miners, standing alongside the drill, guide the steel from in front of the chuck with the left hand while reaching around behind the drill to the leg control with the right hand. This type of collaring posture required miners to have their left and right shoulders abducted 70° and 90°, respectively. Elbows were typically observed to be flexed between 70° and 110°.

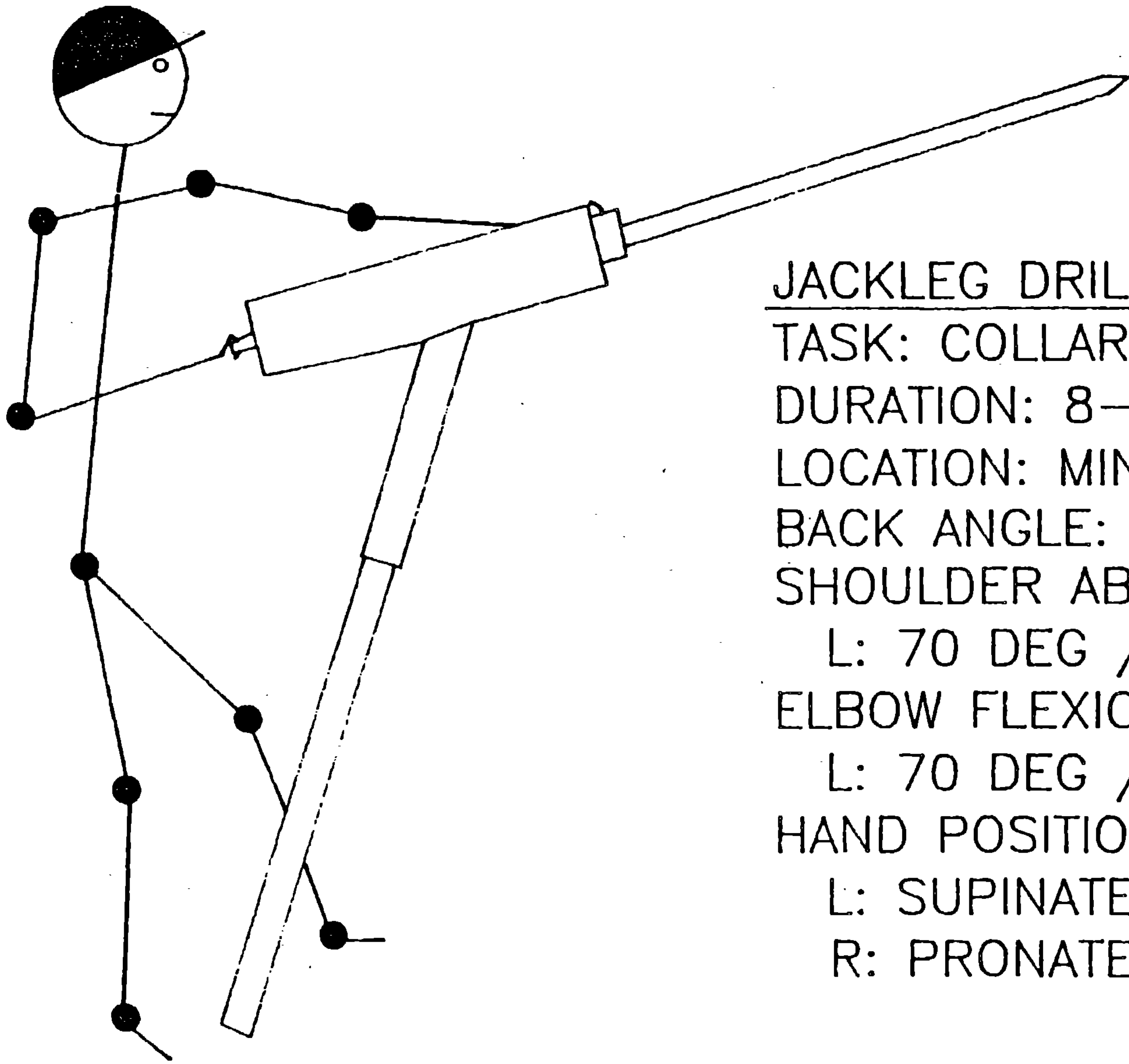
<u>Drilling</u>

Once the hole was started, the operation of the jackleg drill required little muscular force. If operated properly, the drill was pushed into the rock with the air pressure from the pneumatically driven feed leg. Miners were occasionally observed working in completely extended postures when drilling holes high in the rib or in the roof. This situation often required excessive reaches on poor footing conditions. In addition, miners were subjected to substantial vibration from this tool operating at full throttle.



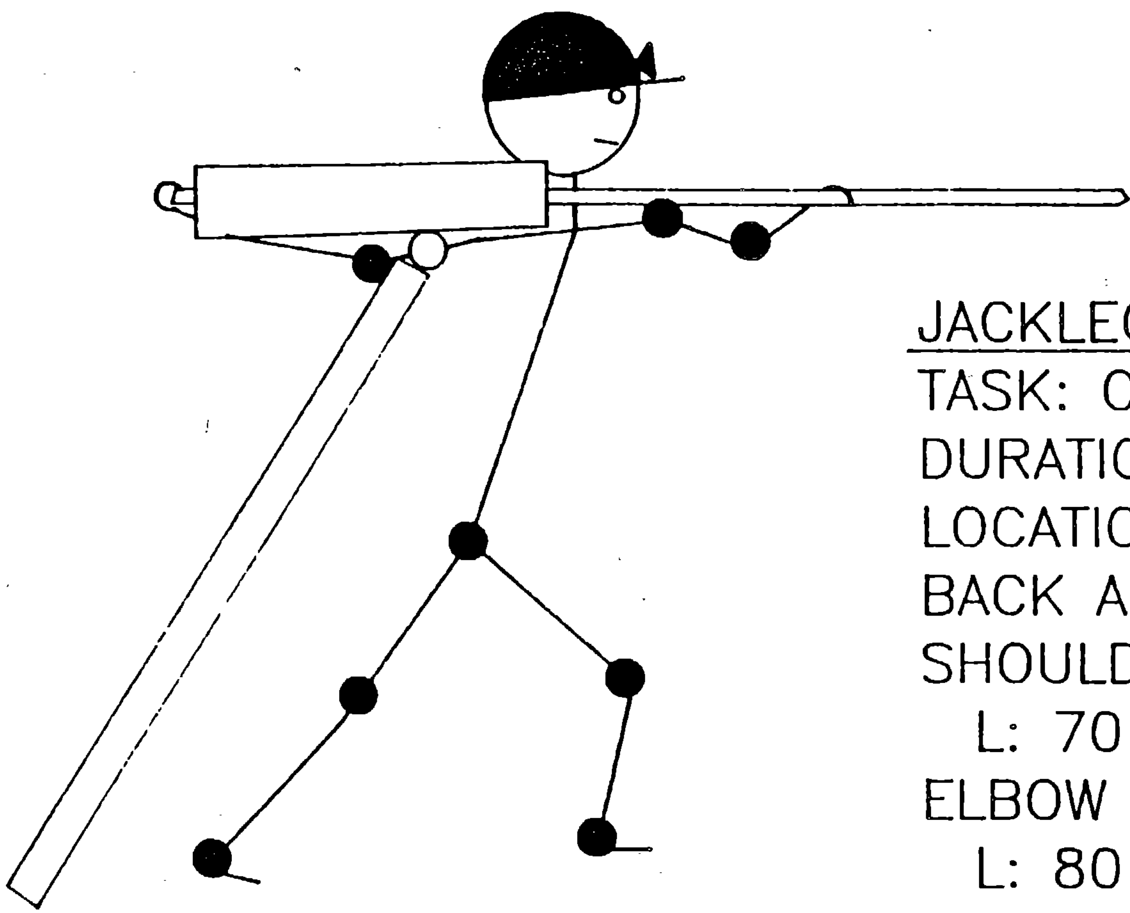
<u>JACKLEG DRILL:</u>
TASK: POSITIONING DRILL
DURATION: 3 SEC
LOCATION: MINE D
BACK ANGLE: −10 DEG
SHOULDER ABDUCTION
L: 80 DEG / R: 20 DEG
ELBOW FLEXION
L: 5 DEG / R: 90 DEG
HAND POSITION
L: SUPINATED
R: PRONATED

FIGURE 4—7: POSITIONING THE JACKLEG DRILL



JACKLEG DRILL:
TASK: COLLARING THE DRILL
DURATION: 8–12 SEC
LOCATION: MINE D
BACK ANGLE: 10 DEG
SHOULDER ABDUCTION
  L: 70 DEG / R: 10 DEG
ELBOW FLEXION
  L: 70 DEG / R: 110 DEG
HAND POSITION
  L: SUPINATED
  R: PRONATED

FIGURE 4–8: COLLARING THE JACKLEG DRILL



JACKLEG DRILL:
TASK: COLLARING THE HOLE
DURATION: 8–12 SEC
LOCATION: MINE A
BACK ANGLE: 20 DEG
SHOULDER ABDUCTION
L: 70 DEG / R: 90 DEG
ELBOW FLEXION
L: 80 DEG / R: 90 DEG
HAND POSITION
L: PRONATED
R: SUPINATED

FIGURE 4–9: ANOTHER COLLARING POSTURE

Pulling the Drill Back

Removing the drill from the hole when the drilling was completed required miners to pull with a substantial amount of force. At lower hole heights, the force was greater than for higher hole heights since the drill had to be lifted during the removal. Typically, the removal was performed from behind the drill by executing a series of motions, whereby, the drill was pulled first with the back, then with the arms. During the back's pull, the shoulders were at approximately 110° of flexion (see Figure 4-10). When the arms were used, the shoulder flexion was reduced during the motion to near 0° and the elbows were flexed to approximately 90°.

Swinging Drill

After the drill had been removed from the hole, it was typically either moved to the next hole location or placed against the wall. The miners observed swinging the drill to the next location usually cradled the drill casing with their left arm and supported the leg control handle with their right hand. This enabled them to pivot the drill on the feedleg while retaining the load close to the body.

Leaning the Drill Against the Wall

Placing the drill against the wall required the miner to lower the drill with his arms and back. Thus, the final posture included the torso bent forward 20° with a twist to the right. Until the weight of the drill was transferred to the wall, the miner was subjected to substantial loading.

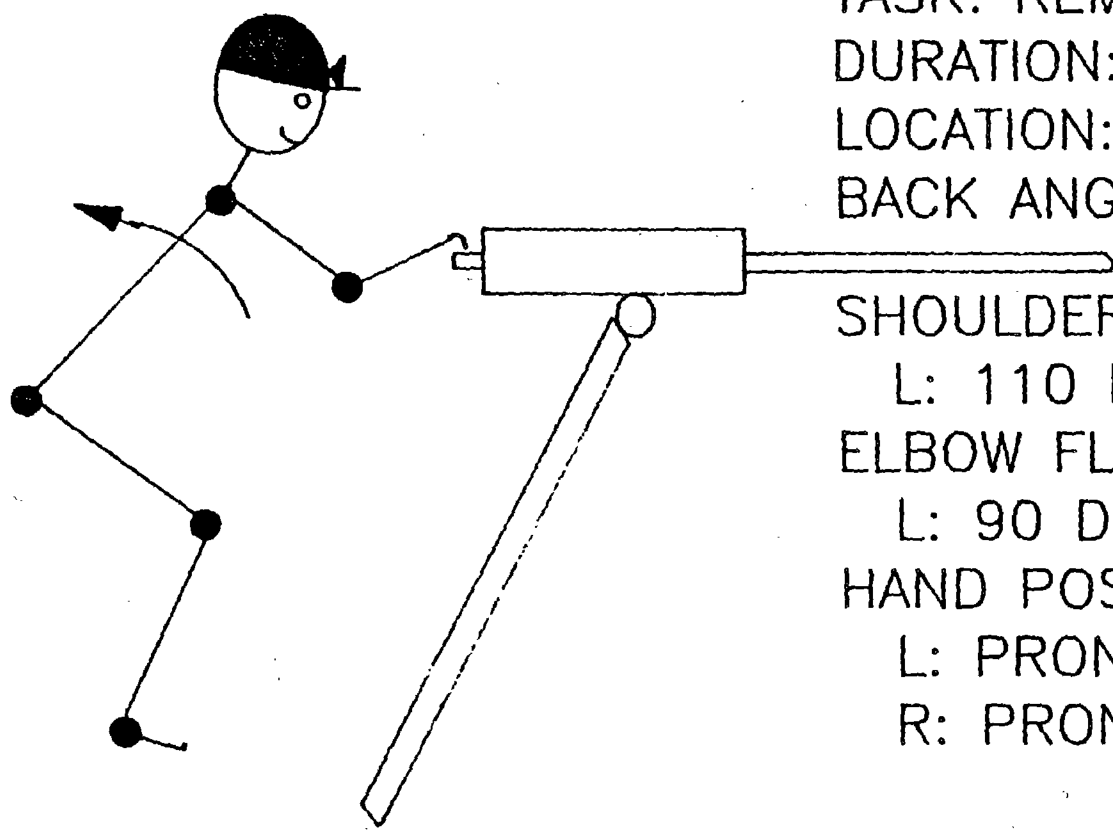
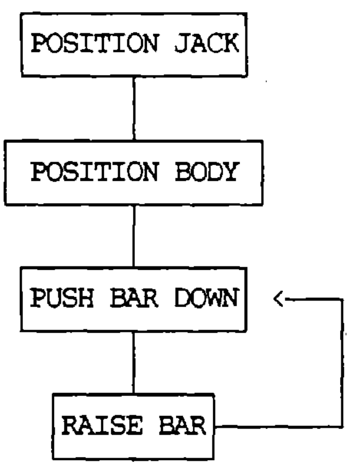


FIGURE 4—10: REMOVING THE JACKLEG DRILL

JACKS

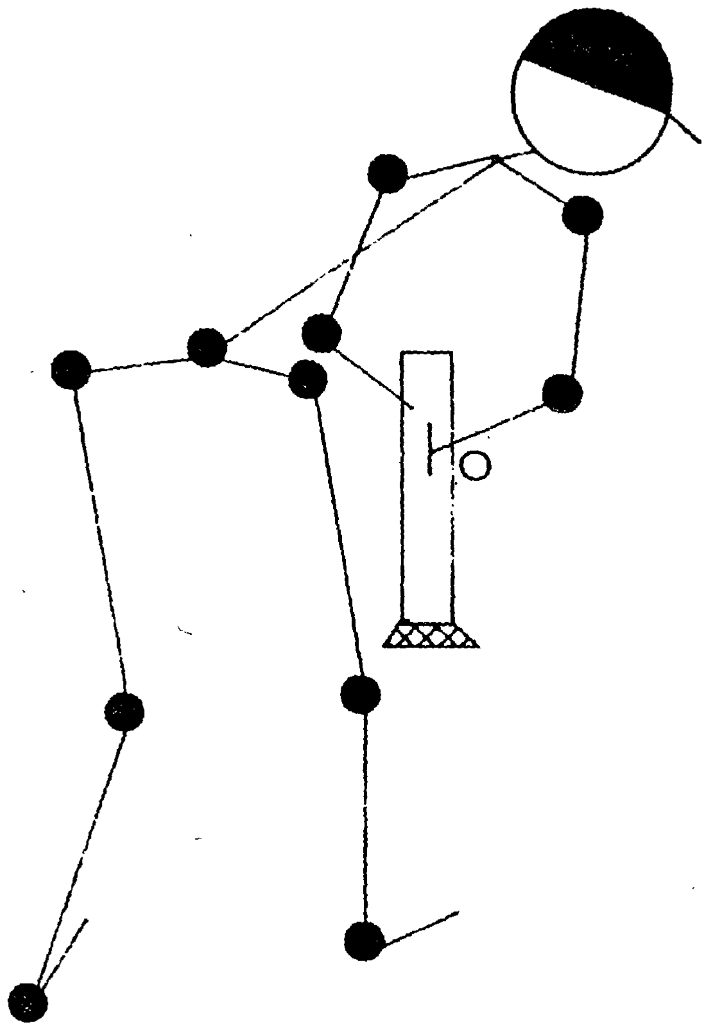
Various types of jacks were observed underground. While roof jacks are heavy (up to 90 lb) and difficult to maneuver in low roof conditions, they are easily set since most are screw-type jacks. The danger in using roof jacks comes from working under unsupported roof conditions, and from the excessive moments created about the spine when manipulating these jacks into position.

Track jacks are used for laying rail, raising timbers, and replacing derailed vehicles on the track. The observations used in this analysis are of the latter when a mantrip was derailed. The basic task elements shown below are essentially the same regardless of the task; however, replacing the derailed vehicle was the most strenuous application of jacks observed. Variations in bar length and the limb used to operate the jack (one miner was observed using a wrench instead of a bar, and then stepping on the wrench to generate enough force to operate the jack) mediate the level of stress on the operator. The basic task elements are shown below:



<u>Positioning Jack and Positioning Body</u>

Positioning the jack often required working in awkward postures. For example, while positioning the jack beneath the front end of a derailed mantrip, the miner was observed to be bent forward 80°, his right shoulder flexed to 100°, and knees bent 45° (see Figure 4-11). Once the jack was placed properly, the miner was observed moving to a posture that would allow the insertion of the bar and operation of the jack.



JACK
TASK: POSITIONING JACK
DURATION: 2 SECONDS
LOCATION: MINE G
JACK WEIGHT: 15.9 KG
BACK ANGLE: 80 DEG
SHOULDER FLEXION
L: 90 DEG / R:100 DEG
ELBOW FLEXION
L: 55 DEG / R: 45 DEG
HAND POSITON
L: ROTATED 90 DEG
R: SUPINATED

FIGURE 4—11: POSITIONING THE JACK

Pushing the Bar Down

While standing to the right of the bar (as viewed from behind), the miner was initially oriented so that his feet were pointing towards the bar. The miner pushed on the bar with only his left hand and used his right hand for balance. As the bar was pressed down, the miner bent his knees and bent his torso forward and to the left (see Figure 4-12). The final posture at the bottom of the action included a trunk flexion greater than 90°, left lateral trunk flexion, and bent knees with the left arm completely extended toward the ground. The right shoulder was abducted 90° as the miner reached to the car to steady the posture. All the force applied to the bar was through the left hand.

Raising the Bar

Although the load was reduced in this task element, the bar must be controlled. If the bar was released at the bottom of the motion, it could pop up and strike the operator. The miner's torso was extended back to a posture of 5° of forward flexion. The knees were straightened and the miner returned to an upright stance.

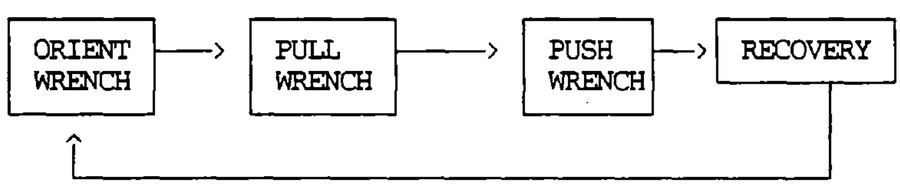
Variations in the Above Cycle

When the load was relatively small and the additional leverage was not necessary, miners have been observed to use jacks with shorter bars. The workers retained static postures of 85° to 95° of forward trunk flexion while operating the tool. The duration of these observed postures was on the order of 10 sec.

WRENCH

Wrenches are used for a variety of tasks in underground mining. A frequent use outside of vehicle repair is laying track. The work postures required to complete the task are more likely a function of the work height and the length of the tool, rather than the roof height.

The elements of the task are shown below:



Typically, several motions are needed to tighten the bolt. This is represented by the direct connection between the recovery element and the orienting element. However, the miner is at greatest risk of exertion injury as the bolt becomes tight.

TRACK JACK:

TASK: PUSHING THE BAR DOWN
DURATION: 0.8 SECONDS
LOCATION: MINE G
ROOF HEIGHT: 2.44 m
BACK ANGLE: 20 – 90 DEG
SHOULDER ABDUCTION
  L: 0 DEG / R: UP TO 90 DEG
ELBOW FLEXION
  L: 80 DEG / R: 15 DEG
HAND POSITION
  L: PRONATED
  R: PRONATED
    USED TO STABILIZE POSTURE

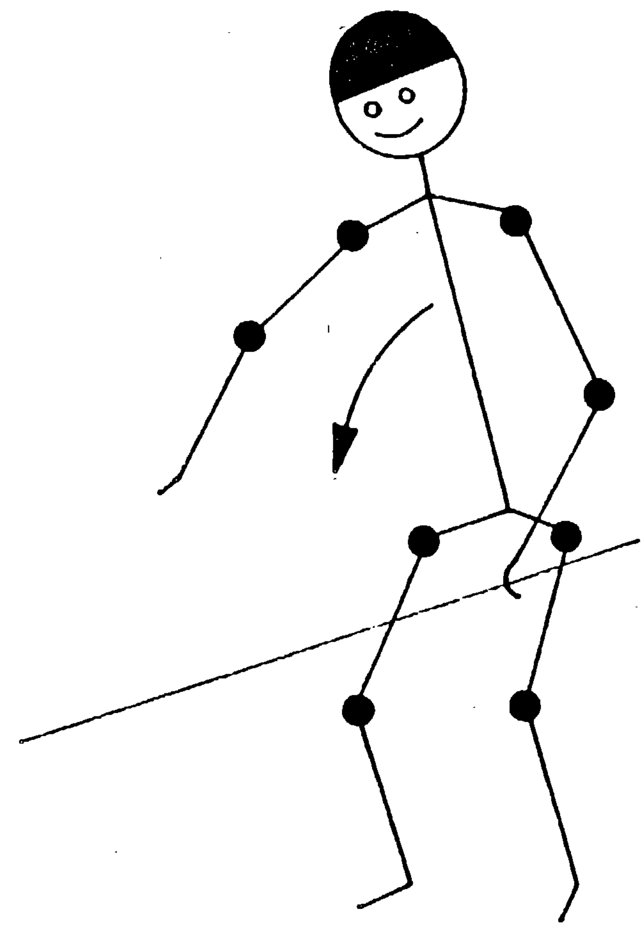


FIGURE 4–12: RAISING TRACK JACK

Orienting the Wrench

In this task element, the wrench was placed on the bolt (or nut). The miner was observed to be in a bent-forward static posture while aligning the tool with the bolt. As shown in Figure 4-13, the miner's trunk was at 90° of flexion and twisted to the right. The feet were about 3 feet apart and the knees were bent approximately 40°. This posture was held for 1 to 2 sec while the wrench was maneuvered into the proper orientation so the maximum stroke could be achieved.

Pulling the Wrench

The wrench was placed on the nut such that the first half of the tightening stroke was a pulling motion and the second half required a pushing motion. The pulling motion was initiated with the wrench between 30° and 40° from the vertical. The initial posture was as described above, 90° of forward trunk flexion and twisted to the right (see Figure 4-14). As the wrench was pulled, the miner remained in the bent over posture, but twisted to the left so as to return to a non-twisted posture. The right leg was extended slightly during the motion to aid in force generation. This resulted in the hips shifting to the left. As the wrench turns, the left elbow showed increased flexion from 15° to 80°, indicating a contribution to the total force from this limb. The right arm remained essentially at a constant flexion, indicating it was used to transfer the force generated by the back musculature. When the bolt was nearly as tight as possible, the miner was observed to jerk on the wrench while in the initial posture.

Pushing the Wrench

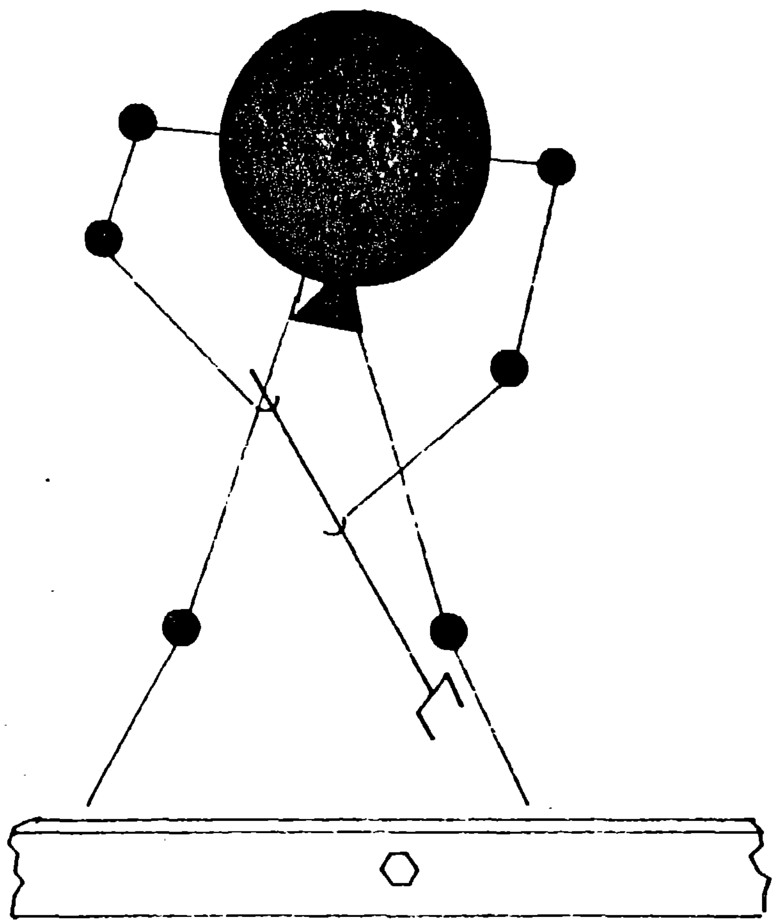
After the wrench reached a vertical orientation, the miner switched from a pulling to a pushing motion. To accentuate the force gained by leaning on the wrench, the miner was observed shifting his body weight further to the left (see Figure 4-15). This was accomplished by extending the right leg to shift the hips even further to the left. The back was still in 90° of flexion, but the miner was now observed twisting to the left as the wrench moved in that direction.

Recovery

At the end of the stroke, the wrench was removed from the bolt. The miner raised his trunk and swung back toward the right. This motion was continued as described in the orientation element if additional strokes were required.

Variations Observed in the Kneeling Work Posture

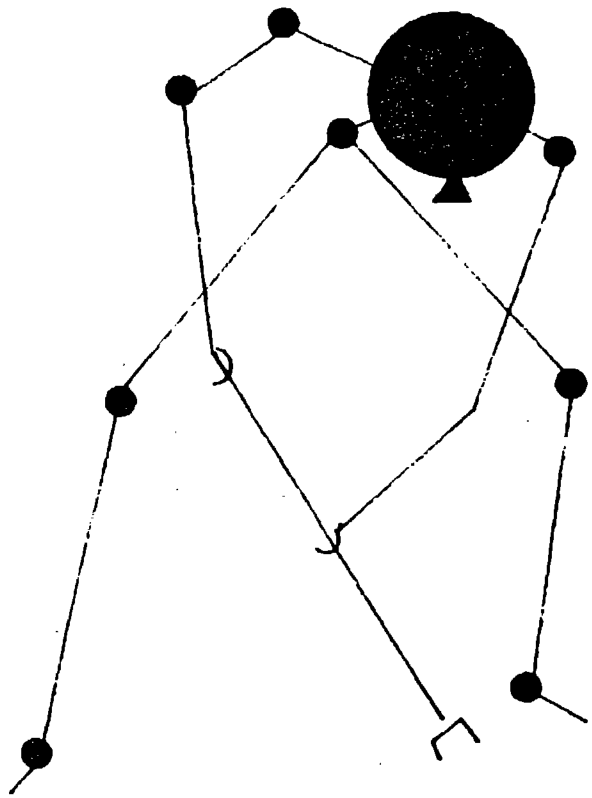
Tightening bolts from the kneeling posture required the miners to maintain a work posture with 35° degrees of trunk flexion (see Figure 4-16). During each stroke, the trunk was bent laterally to the left. Since the miner's weight could not be transferred during each stoke as in the standing posture, less tightening power was available while kneeling. This could lead to a greater loading to the lower back from the trunk musculature and possible low-back problems.



WRENCH:

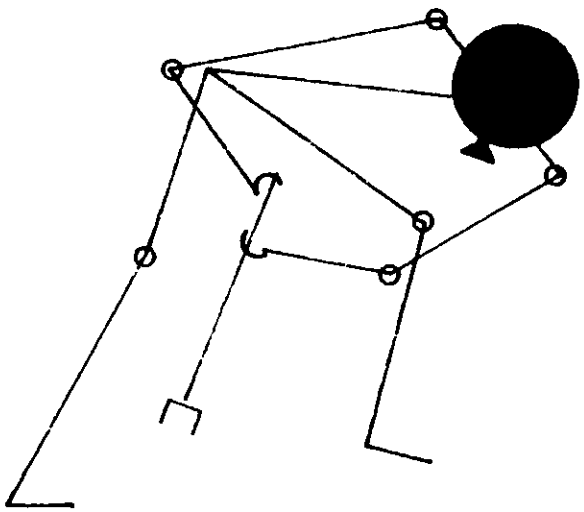
TASK: ORIENTING THE WRENCH
DURATION: 1–2 SEC
LOCATION: MINE G
BACK ANGLE: 90 DEG
SHOULDER FLEXION
L: 30 DEG / R: 10 DEG
ELBOW FLEXION
L: 60 DEG / R: 90 DEG
HAND POSITION
L: PRONATED
R: SUPINATED

FIGURE 4–13: ORIENTING THE WRENCH



WRENCH:
TASK: PULLING THE WRENCH
DURATION: 0.3 SEC
LOCATION: MINE G
BACK ANGLE: 90 DEG
WRENCH ANGLE: 35 DEG
SHOULDER FLEXION
  L: 90 DEG / R: 10 DEG
ELBOW FLEXION
  L: 15–80 DEG / R: 90 DEG
HAND POSITION
  L: PRONATED
  R: SUPINATED

FIGURE 4–14: PULLING THE WRENCH



WRENCH:
TASK: PUSHING THE WRENCH
DURATION: 0.9 SEC
LOCATION: MINE G
BACK ANGLE: 90 DEG
SHOULDER FLEXION
L: 25 DEG / R: 20 DEG
SHOULDER ABDUCTION
L: 20 DEG / R: 20 DEG
ELBOW FLEXION
L: 80 DEG / R: 90 DEG
HAND POSITION
L: PRONATED & ROTATED 90 DEG
R: PRONATED

FIGURE 4—15: PUSHING THE WRENCH

WRENCH:

TASK: TIGHTENING BOLT
DURATION: 0.6 SEC
LOCATION: MINE E
BACK ANGLE: 35 DEG
SHOULDER FLEXION
  L: 20 DEG / R: 20 DEG
ELBOW FLEXION
  L: 60 DEG / R: 90 DEG
HAND POSITION
  L: SUPINATED
  R: SUPINATED

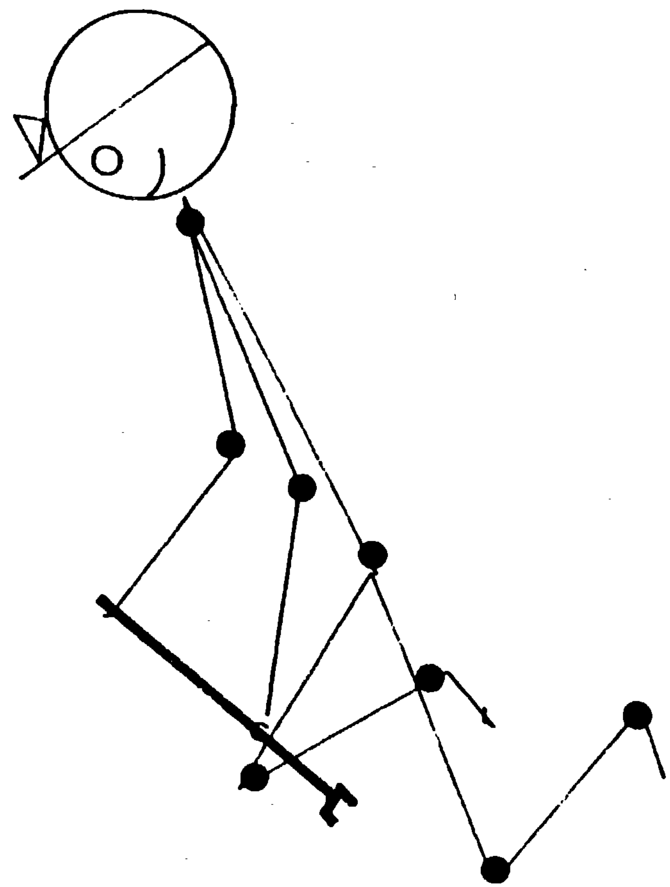


FIGURE 4—16: USING WRENCH IN KNEELING POSTURE

PRY BAR

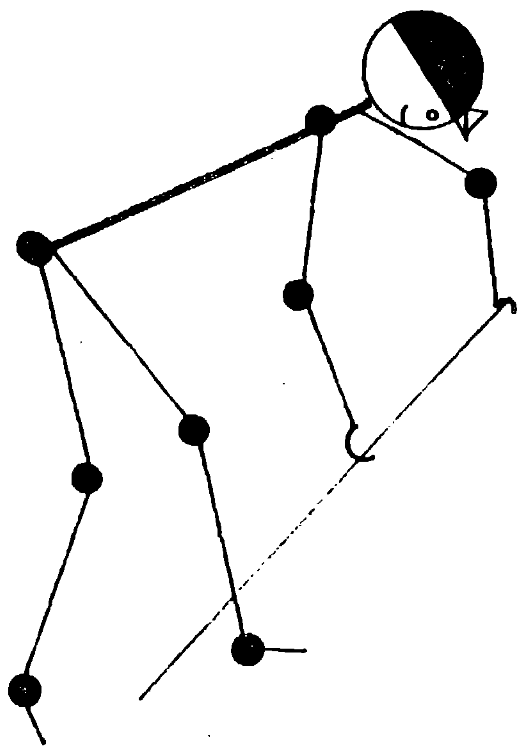
Pry bars were observed while maneuvering rail during track laying operations and when maneuvering equipment that was too heavy to lift. In both cases, the task elements were the same: orientation, prying, and removing of the bar.

During orientation, the bar was positioned to provide adequate leverage. This often required bending forward up to 90° and extending at least one of the arms (see Figure 4-17). The final posture in this task element was the initial posture for the prying element. In low-load conditions, such as when rail was being maneuvered, the prying force was generated mostly with the arms. Under higher-load conditions, the prying force was generated with the trunk musculature. However, in all the prying tasks observed, the trunk flexion initially was in excess of 70°.

HAMMER / AXE

A variety of hammers were observed underground in a variety of tasks. Sledge hammers, axes, and spike mauls were seen being used in breaking large rocks, carpentry, and maneuvering track into the desired location. Some of these tasks were performed in kneeling, as well as standing, work postures.

Essentially, the task can reliably be broken into three elements: the raising of the hammer (or the back swing depending on the orientation), the driving swing (see Figure 4-18), and the recovery. Raising the hammer pulls the head far enough away from the target so that adequate acceleration of the head can be achieved. During the swing, one aspect appeared consistently from one hammering task to another. Often, the initial part of the swing was generated in the shoulders and the elbows. The final phase of the swing was almost invariably generated with a "snapping" of the wrists. This motion typically resulted in substantial (up to 30°) ulnar deviation of the wrist. Typically, during the recovery phase, the tools were brought in close to the body before being raised in preparation of the next swing.



PRY BAR:

TASK: INSERT/POSITION
DURATION: 0.5–1.0 SEC
LOCATION: MINE G
BAR WEIGHT: 3.6 KG
BACK ANGLE: 85 DEG
SHOULDER FLEXION
  L: 90 DEG / R: 90 DEG
ELBOW FLEXION
  L: 50 DEG / R: 15 DEG
HAND POSITION
  L: PRONATED
  R: SUPINATED

FIGURE 4–17: USING THE PRY BAR

HAMMER/AXE:

TASK: SWINGING HAMMER
DURATION: 0.4 SEC
LOCATION: MINE E
HAMMER WEIGHT: 3.6 KG
BACK ANGLE: 30–80 DEG
SHOULDER FLEXION
L & R: 30 TO 45 DEG
ELBOW FLEXION
L & R: 90 DEG TO 45 DEG
HAND POSITION
L: AT END OF HANDLE
R: 10 CM ABOVE L GRIP
WRISTS ABDUCTED AT END OF SWING

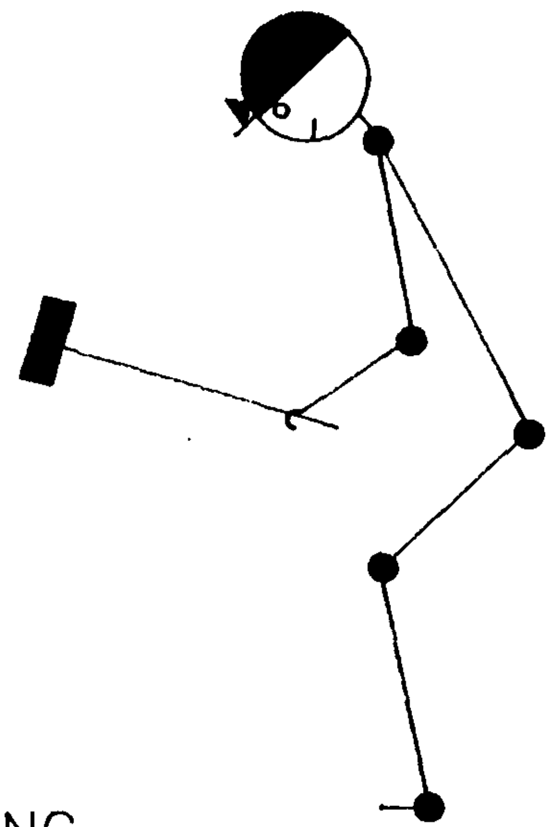


FIGURE 4–18: SWING SLEDGE HAMMER

CHAPTER 5: ERGONOMIC ANALYSIS

SCALING BAR

The most frequent type of scaling bar accident in both coal and metal-nonmetal (MNM) mining are struck-by accidents. Specifically, struck-by accidents account for 79% and 75% of all scaling bar accidents in coal and MNM mining, respectively. Narratives from accident reports and interviews with miners identified that the primary mechanism involved in these injuries was falling debris. Scaling requires miners to work under roof conditions that usually have not been secured. Several hypotheses have been generated as to this high incidence rate of struck-by injuries.

First, the illumination supplied by a caplamp is usually considered to be inadequate for any setting other than a focused beam. Therefore, much of the falling debris that contacts a miner is likely to remain undetected, or detected too late for an evasive response to be initiated. This indicates that there is a need for a lamp design that adequately illuminates the peripheral regions, while at the same time maintaining adequate task illumination. Perhaps this will take the form of a two bulb lamp, where one bulb is used in the generation of a forward beam, while the second bulb is used in the generation of an upward and more dispersed beam. This would aid in the earlier detection of falling debris.

Second, it is thought that miners are often working with scaling bars that are too short. This results in miners scaling closer to the target area. Once debris is loosened, the miner is more likely to be struck when it falls. Longer bars, or possibly telescoping bars, may be the necessary solution to this problem.

A third hypothesis along these lines concerns the role of fatigue when scaling. It is hypothesized that as miners scale and become fatigued, energy is conserved by working with the bar in a more vertical orientation. This suggests that as miners become tired, they tend to work closer to the falling debris. Furthermore, as miners become tired the response time to falling debris is likely to be slowed and possibly inadequate.

While the frequency of exertion injuries with scaling bars is small relative to struck-by injuries, their incidence may be related. A large external moment is imposed by the scaling bar. This is due to the center of gravity of the bar being held out in front of the miner. To compensate for the torque generated about the L5/S1 disk, greater muscular force from the posterior muscle groups in the torso is necessary. This increased muscle force in the low back region and the upper torso would be expected to increase the rate of fatigue, and possibly lead to the behavior hypothesized above.

Thus, to keep the miner out from under the falling debris and reduce the loading on the spine, it is suggested that scaling bars be counterbalanced. This shift in the weight distribution of the bar should retain the strike power of the bar, while moving the center of gravity closer to the user, thereby reducing the internal forces needed to stabilize the working posture.

Work postures assumed by miners underground differ from those presented in training presentations (slide presentation on Jackleg Drill, available for preview from Bureau of Mines, Pittsburgh Research Center). The recommended posture of the upper arm is to abduct the forward shoulder in excess of 90° and use a pronated grip over the bar. Two explanations were given for the use of this posture. First, the arm in this posture requires miners to work further from the target area since the bar angle is further from vertical. Second, the arm in this posture could be used to deflect falling debris before striking the torso. While the benefits of this work posture are clear, it was rarely observed underground. This suggests that miners prefer working with the left shoulder abducted less than 90° and with a supinated grip.

Empirical investigation should be useful in describing the physiological cost in terms of muscle force that is required for both of these postures. In addition, studies should investigate the relative muscular force requirements of variations in bar design and their resulting strike forces.

JACKLEG DRILL

The jackleg drill accounted for better than 18,000 lost days during the six-year period 1978-1983. As with the scaling bar, the struck-by injury was the most frequent. The struck-by injury comprised the largest percentage of lost days, followed by the exertion type injury.

Analysis of narratives from jackleg drill accidents indicates the most frequent type of struck-by injury entails rock falls. Other typical scenarios include falling drill steel and falling drills. The limited illumination mentioned in conjuction with the scaling bar struck-by accidents is also relevant to accidents involving the jackleg drill. The lack of peripheral illumination makes falling debris extremely difficult to detect. Moreover, the noise created by the drill would mask any audible stimuli predictive of rock falls. Once again better worksite lighting conditions may help in alleviating rock falls as a source of injury in the struck-by accident.

The prevalence of exertion injuries is thought to be related to the weight of the drill. Typically, jackleg drills weigh between 100 and 120 lb. This necessitates large muscular forces when manipulating the drill. These internal forces, in turn, place excessive loadings on the spine. For example, using the Chaffin model (Chaffin and Andersson, 1984) to estimate compression in large males while picking up the jackleg drill yields values in excess of the maximum permissible limit set by NIOSH (1981). Presently, jackleg drills are constructed with steel casings. This casing contributes substantially to the overall tool weight. Therefore, design of an aluminum casing should reduce the tool weight; this will reduce the corresponding muscle forces generated when handling the tool, and thus reduce some of the risks associated with the use of the tool (Fraser, 1980). However, the durability of an aluminum drill casing has not been investigated.

The exertion injuries to the trunk were most prevalant in the removal phase of operating the jackleg drill. Task analyses show that this entailed repeated trunk extensions as the steel is withdrawn from the hole. Should the steel become hung-up (stuck) during the removal process, sudden unexpected loading to the biomechanical system could occur. Several authors have shown that sudden loading conditions can lead to both extreme muscular contractions (Marras, Rangarajulu, and Lavender, 1987; Lavender, et al., 1987) and increased risk of back injury (Manning, Mitchel, and Blanchfield, 1984).

The drill removal task is likely to be most strenuous when the steel is being removed from a lower hole in the rock face. Under this condition, the drill must be pulled and lifted simultaneously. It is hypothesized that an additional handle mounted on top of the drill casing will aid in reducing the effort needed to remove the drill, especially from the lower holes.

Positioning the drill, as descibed in the task analysis, requires the miner to manhandle the drill into a proper orientation for drilling the next hole. The weight of the casing is once again a factor in the muscular force needed to perform this task. Lighter drill bodies should be easier to maneuver and decrease the incidence rate of low-back pain associated with this tool. However, lighter drills may not offer the stability necessary for adequate control of the drill. Even though lighter drills would aid in positioning and handling, there is probably an optimal weight for the drill. If the drill were to weigh less than that amount, then the muscle force might be expected to increase as the control problems increase.

Drill collaring places the miner in a static and often extended posture. Many miners were observed to keep their left hand on the drill steel and their right hand on the leg control. Task analyses indicate that this posture requires the miner's right arm to be abducted 90°, and the right elbow flexed approximately 150° so that adequate drill leg control can be attained. As a result, this situation leaves the miner in an overall work posture that does not allow for the control of the jackleg drill should it begin to fall sideways. Narrative accounts of accidents indicate that struck-by and caught type accidents were frequently caused by falling jackleg drills. Once again, a handle on top of the drill casing may allow adequate control of the drill during collaring and in unanticipated situations.

Although no quantitative measures were made concerning the vibration levels encountered during jackleg drill operation, many of the miners interviewed indicated troubles with numbness and tingling in the fingers. Raynaud's phenomenon, a cumulative trauma disorder due to continual exposure to vibration, has been documented in drill operators (Brubaker, Mackenzie, Hutton, 1986) and chain saw operators (Taylor, Pelmear, and Pearson, 1974). Taylor et al. (1974) showed that antivibration saws were effective in reducing the symtoms of vibration-induced white finger disease in chainsaw operators. Thus, similar modifications of the jackleg drill are recommended.

JACK ACCIDENTS

In the coal mining industry, jack accidents accounted for 22,205 lost days over the 6-year period 1978 through 1983. Exertion injuries account for 44.5% of this lost time. As shown in the first phase of this project, exertion-trunk-tear jack accidents have the highest total lost days for any handtool accident scenario in underground mining. The average lost time associated with this scenario is 29.81 days, for 277 occurences.

A miner was quoted as saying, "We use the rail jack for just about every task that requires a jack, even if that jack is not the best kind to use ...". The design of the rail jack is similar to the traditional tire jack design where the jack handle raises a notched shaft until its groove is caught by a spring-loaded catch. Accident narratives indicate that caught fingers are a frequent occurrence with the use of jacks. The statistical analysis conducted during phase one indicates that better than 14% of the jack accidents could be so described. This suggests the need for a covering plate over the mechanism to prevent finger access.

Jack exertion injuries, as described by accident narratives, occur either through the handling or operation of the jack. Several narratives describe exertion injuries to the lower back as a result of lifting jacks. Jacks used in coal mines for laying track weigh approximately 35 lb, while roof jacks typically weigh between 60 and 75 lb. However, track-jacks tend to be more versatile and, therefore, are used most often by miners. Task analyses have documented their use in laying track and maneuvering derailed vehicles.

During positioning of the jack, the miner's torso is bent forward in excess of 80° from the vertical and arms are typically outstretched. This posture, in addition to the forward torque attributable to the jack itself, increases the torso's moment about the lower spine relative to postures with less flexion of the torso and the shoulders. Thus, miners should be encouraged to work with knees bent or even a kneeling posture when working the jack into position.

In addition, miners should be trained in the adequate placement of jacks and encouraged to spend the necessary time to make sure the jack is stable. Narratives indicate a sizable percentage of the struck-by accidents occurred because of inadequate placement and the subsequent "kicking out" of the jack.

The exertion-trunk-tear injury may result when the miner is using the jack to move a heavy load. Task analyses have shown that while working with heavy loads, the miner's back bends from 5° (handle up) to 95° (handle down) with increasing acceleration. As the handle moves toward the down position, the miner encounters greater resisting force which is virtually eliminated when the jack catches.

Three mechanisms of injury have been hypothesized to account for these accidents. First, injuries may occur following the sudden release of opposing force (i.e., due to the braking of trunk motion). Second, injuries may result from the abrupt motions made by a miner attempting to avoid a jack handle that did not catch or that slipped from its groove (similar to back injuries that are reported during slips and trips, see Manning, Mitchell, and Blanchfield, 1984). Third, injuries may be caused by overexertion while pushing down on the handle before the jack catches. To alleviate these problems, hydraulic jacks are recommended.

Hydraulic jacks typically have constant force requirements throughout the entire stroke. In addition, the stroke size is variable and can be adjusted to fit the task. With any type of jack, however, the bar length must be adequate to provide enough leverage so that it can be easily operated.

Statistics collected from 1978 to 1983 show that 9236 lost days were the result of struck-by injuries for jack accidents in coal mines. Narratives illustrate that many of these injuries were inflicted by the jack handle striking the miner. However, in MNM mines the number of jack accidents due to "struck-bys" over the same period is very small. The difference may be a result of the height of the seam. The constrained work postures in low-seam conditions are seen as a potential hazard when operating track jacks. There may be insufficient space to work in a safe orientation relative to the tool. Once again the use of hydraulic jacks is recommended as a solution to the problem. The hydraulic jack has no predetermined stroke length so the handle will remain wherever the stroke is discontinued. Telescoping bars are recommended so that the maximum amount of leverage can be achieved within the necessary space constraints.

WRENCH ACCIDENTS

Miners use wrenches for a variety of tasks while working underground. Mine visits made during the second phase of this project have documented the tool's use in laying track, roof and rib bolting, hose connection tasks, drill steel removal, and substitution as a jack handle or a hammer.

Accidents involving wrenches number 430 for coal mining and 189 for MNM mining during the six-year period 1978 through 1983. Exertion injuries account for more than half of the lost time associated with this tool. The largest portion, 65%, of the 4442 days lost due to exertion injuries can be attributed to the 136 injuries (combined MNM and coal) classified as exertion-trunk-tear accidents.

Further analysis of the coal mining accident data failed to support the inclusion of seam height as a contributing factor in wrench exertion-trunk-tear injuries. This null effect of seam height on wrench exertion injuries suggests that the typical posture assumed by miners when using wrenches is either kneeling or stooped. This would be true for many tasks in which wrenches are used, such as in laying track or fixing equipment.

Task analyses of miners using wrenches when laying rail show that exertion injuries to the trunk are likely when the miner is nearly finished tightening a bolt. This is when the forces exerted on the wrench are at a maximum. For both the stooped and kneeling postures, tightening the bolt was composed of two phases. First, the wrench was pulled until it reached a vertical orientation. Second, the miner would change positions and push the wrench through the remaining stroke.

In the stooped position, the miner is capable of distributing the load between the arms, legs, and trunk. In the kneeling posture, the legs cannot aid in force generation, so the back must supply the force on the wrench and also maintain a stable posture. In addition, the kneeling posture requires more lateral bending of the trunk as the hips can not be shifted. Thus, relative to the stooped posture, the kneeling posture should show increased muscle activity in the lower back and lower force output as measured by the torque generated on the wrench. This increased muscle force can be expected to increase the compression on the spine. The use of longer wrenches could be expected to decrease the internal muscular forces in both postures. In either posture, the longer tool gives increased mechanical advantage and aids in maintaining erect work postures.

Another likely source of exertion injuries, as well as struck-by injuries, is the scenario where the wrench slips. Large forces in the antagonistic musculature and in those muscles required in maintaining balance would be expected. Manning et al. (1984) demonstrated an increase in back injuries resulting from similar unexpected events. Likewise, other researchers have indicated that under unexpected sudden loading conditions, trunk muscle response increases the estimated compression of the spine by at least a factor of two (Lavender et al., 1987). Since the wrench-slipping scenario is frequently reported in the accident narratives, miners may flex the antagonistic muscles slightly in preparation for this event. This type of preparatory response would result in further loading of the spine whenever the task is performed. One possible remedy is the employment of wrenches with locking cams. These tend to reduce the occurrence of wrench slips.

HAMMER /AXE /SPIKE-MAUL

In the coal and MNM mining industries, statistics collected from 1978 to 1983 show 13,007 lost days due to injuries while using a hammer, axe, or spike-maul. For both industries, the most frequently reported accidents are "struck-bys" to the miner's arm that result in a broken bone or a cut. In coal mining, struck-by accidents account for 7857 of the 11,105 lost days attributable to hammering tools. Narratives support the case where miners strike their hands while using one of the above tools. In addition, exertion-trunk-tear injuries account for about 20% of the lost days for both industries.

Task analyses suggest that coal miners may be restricted in their swing due to seam height. Thus, there may be a tendency to use more muscle force to accelerate the hammer than would be necessary in comparable tasks in higher roof conditions.

As mentioned in the task analysis section, several miners using various types of hammers were observed snapping their wrist at the end of each stoke. While increased power may be obtained from the stroke, it may be at the risk of a cumulative trauma disorder. Repeated ulnar deviation of the wrist has been identified as an occupational risk factor in the development of tenosynovitis (Chaffin and Andersson, 1984; Tichauer and Gage, 1978). A potential solution is to use bent handles (Konz, 1986; Konz, 1983) that keep the wrist straight through the swing. Empirical investigation is necessary to determine if this will affect the power developed in the swing.

PRY BAR

The pry bar is used for a variety of tasks in underground coal and MNM mining. Observations made during the mine visits demonstrated its use in maneuvering heavy equipment and positioning rail. The statistical analysis showed that the most frequent type of injury with pry bars was the struck-by. This accounts for approximately half of the pry bar injuries in both coal and MNM mining. Narratives from accident reports indicate that a frequent scenario is when the bar slips out from under the object being hefted and strikes the miner.

The second most frequent type of injury is exertion. This composes 33% and 26% of the pry bar injuries in coal and MNM mining, respectively. While a small percentage of exertion injuries are to the arm, the overwhelming amount involve the torso. The general scenario is that miners overexerted themselves while trying to lift an object.

The task analysis indicated two problem areas associated with the use of this tool. First, the user must bend forward in excess of 90° while the tool is being positioned. In addition to the large moment created about the spine due to the torso posture, the arms and the tool are usually out in front of the miner, thereby increasing the magnitude of the torque about the L5/S1 disk. Second, most of the prying force would be generated during the initial action of the prying phase. During this period, the miner is working to overcome the inertia of the object being maneuvered. Unfortunately, this is usually when the prying posture shows the most trunk flexion. Thus, the power generated by this posture is often developed by the back musculature (Rockwell and Marras, 1986).

Ideally, a posture using the power of the leg muscles should serve to reduce the incidence of exertion injuries. This may be accomplished by the use of a "racheted" prybar. Such a tool would allow users to adjust the tool so that the maximum prying force could be obtained with the minimum amount of stress on the trunk. Figure 5-1 shows a diagram of this tool. While this tool would be suitable for crews laying track, most prybar use occurs at unexpected times with whatever type of bar is available. In this case, injury prevention is only likely to be possible through the training of miners as to low-risk work postures.

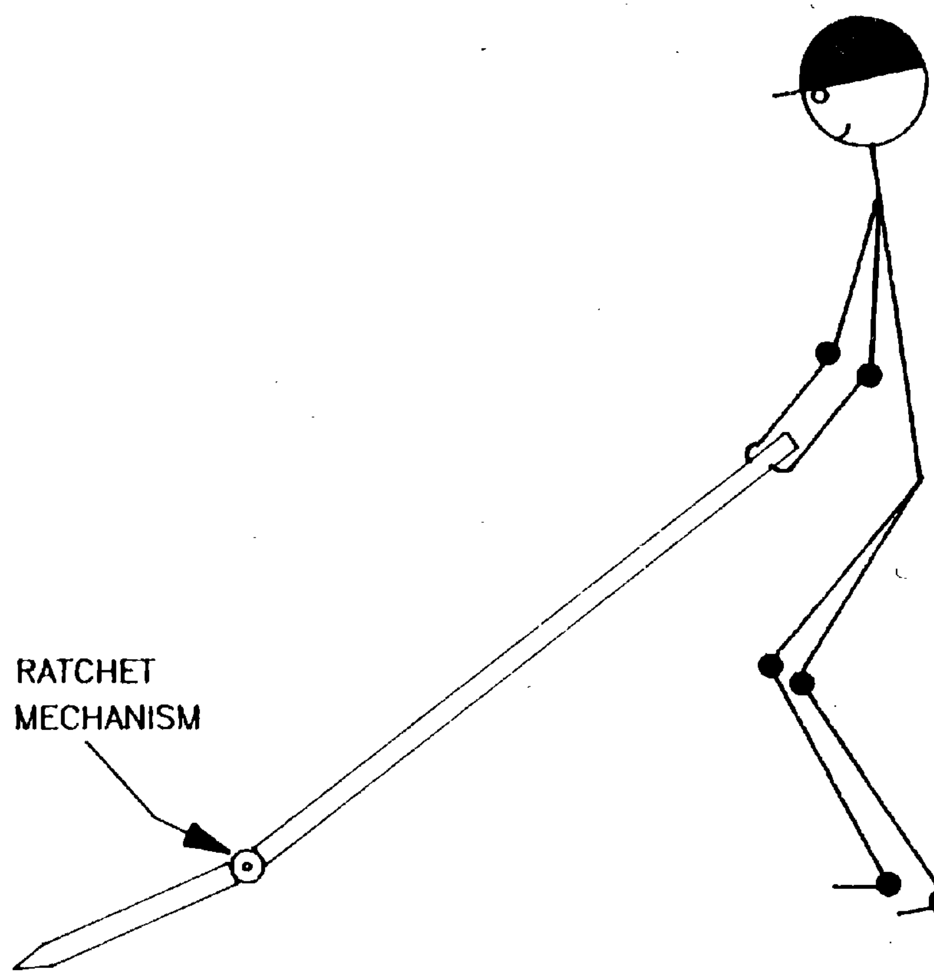


FIGURE 5—1: RATCHETED PRY BAR

KNIFE

While the knife was frequently involved in handtool accidents in underground mining, the severity of each accident, in terms of lost time, was low. The high incidence of cuts is likely related to the use of the knife as a general tool for cutting, scraping, stripping, and substituting for the proper tool. In addition, the poor illumination at worksites in underground mining is likely to be a factor in the high frequency of knife accidents.

Two solutions can be proposed with regards to the problem of frequent hand cuts. First, where applicable, miners should use knives with a pistol grip (Cochran, and Riley, 1986b). This grip can include a guard to protect the miner's hand, but will also aid in keeping the wrist straight, thus reducing the incidence of cumulative trauma disorders. Second, steel mesh gloves are available that would protect the user's hand if the knife slipped.

CHAPTER 6: SCALING BAR EXPERIMENT

INTRODUCTION

Previous research using statistical analyses has identified tool use scenarios often leading to injury when using the scaling bar (Lavender, Marras, Lundquist, and Rockwell, 1986). Relative to other handtools used in underground mining, the scaling bar ranks highest on days lost from work in coal mining and second, only to the jackleg drill, on days lost from work in metal-nonmetal mining. In both coal and metal-nonmetal mining, scaling bar accidents have the highest average lost days per accident of all handtools used underground (Marras, Lundquist, and Rockwell, 1986). The focus of the scaling bar experiment is to empirically investigate the exertion injury mechanisms while using this tool.

Underground observations and subsequent task analyses indicated variations in method of tool use for accomplishing similar tasks. These variations are not necessarily in agreement with the method suggested in training presentations used by the Bureau of Mines. This latter method requires the miners to have their elbows pronated and above shoulder height. The purpose of this position is to allow the miner to be further from the scaling target and put the forearm in a position where falling debris can be deflected before striking the torso or head. This method, while recommended, was not commonly observed. The most frequent method of scaling bar use observed underground had the miner working with a supinated grip and the forward upper arm not abducted while in the resting position.

The scaling bars used underground varied along the dimensions of length, weight, and diameter. The length is a critical measure since this affects how close the miner has to be to the loose roof material when scaling. The weight of the bar determines the external loading placed on the miner during the orienting, thrusting, and recovery phases of the task. Decreasing the bar weight, thereby decreasing the inertia of the bar, should affect the strike force between the bar and the rock. Suggested modifications to the bar involved the use of counterbalancing to maintain an effective bar weight while bringing the center of gravity of the worker-bar system closer to the spine.

Underground mines vary greatly in roof height from approximately 30 in to 12 ft or better. The work postures related to roof height may be a contributing factor in the etiology of scaling exertion injuries. Lower roof heights require miners to work in kneeling or stooped postures imposing larger loads on the spine (Gallagher, 1987).

The following experiment was designed to test these factors and their relation to the muscular force required to complete a scaling task. The goal was to gain a basic understanding of how the body responds to these factors. Specifically, the following research study addressed whether differences can be observed in levels of muscle activity as a function of the method of scaling used, the type of bar used, and the height of the roof (and thereby the work posture used) when the task is performed.

Subjects

Fourteen male subjects volunteered their services for the study. Only two subjects (both former miners) had some previous experience scaling in an underground environment. For this subject pool, the mean height was 177.2 cm (s=12.3 cm), and the mean weight was 79.12 kg (s=11.88 kg).

Experimental Design

The independent variables investigated in this study consisted of method of using the bar (2 levels), bar type (3 levels), and roof height (2 levels). Thirteen dependent measures were recorded. These were mean and peak electromyographic (EMG) signals from the following six muscles:

1. Left Latissimus Dorsi (LATL) and Right Latisimus Dorsi (LATR)
2. Left Erector Spinae (ERSL) and Right Erector Spinae (ERSR)
3. Left Rectus Abdominus (RCAL) and Right Rectus Abdominus (RCAR)

In addition, the strike forces were collected from a three-axis dynamometer.

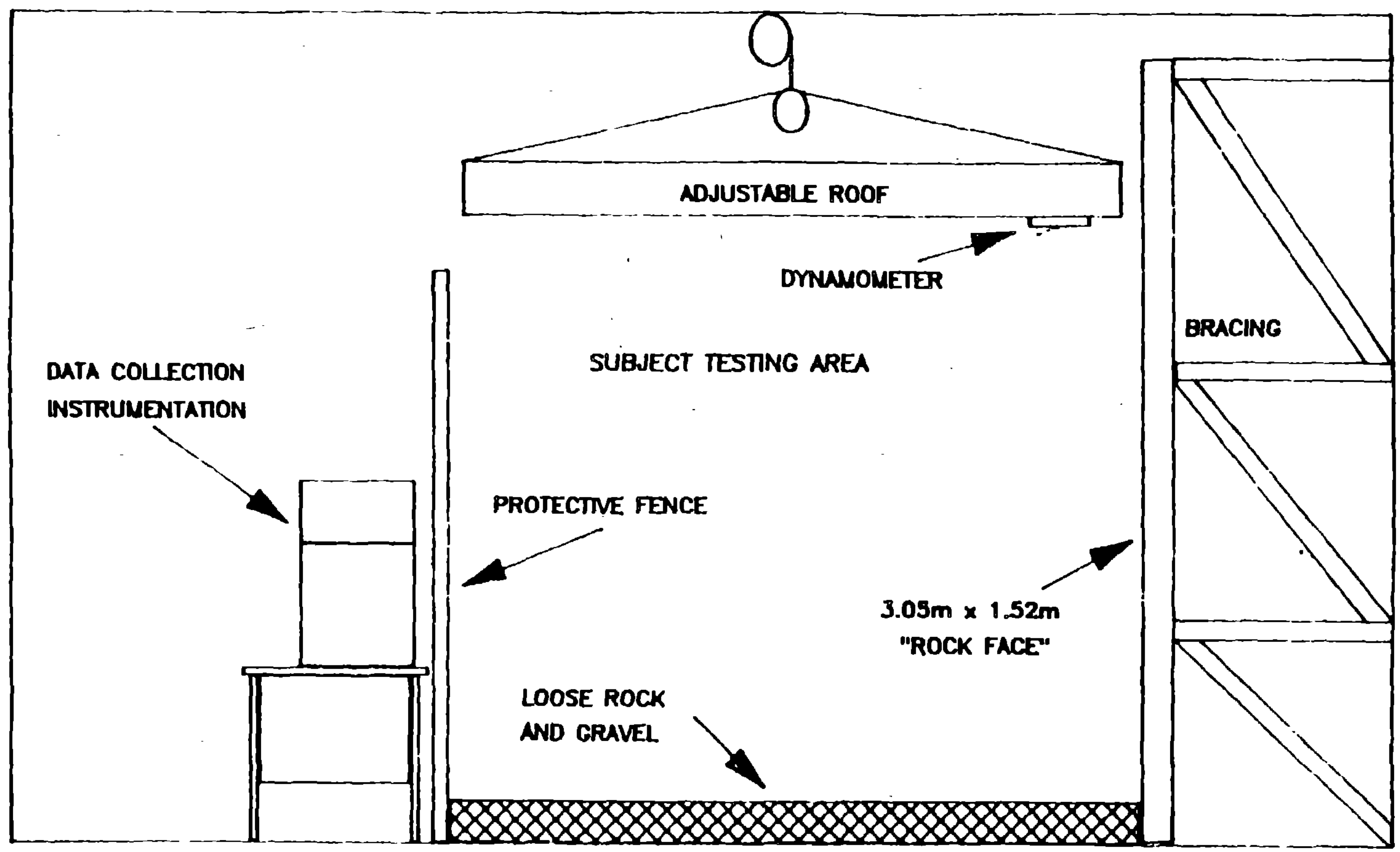
The experiment was blocked on roof height while the sequence of bar type and method of testing was randomized. The experiment was a repeated measures design with all subjects participating in all cells of the experiment.

Apparatus

Testing was conducted in a simulated mine environment (see Figure 6-1). The front of the mine had a 9 cm wooden wall serving as the working face. An adjustable ceiling was designed to simulate the varied roof conditions. In this experiment, the roof height was adjusted to either 141 cm (55.5 in) or 251 cm (98.8 in). The floor was covered with approximately 10 cm of gravel to simulate the loose, irregular surface miners typically stand on. Bolted to the roof was a 3-axis dynamometer that served as a target in the scaling task.

Three scaling bars were used. The first, which is referred to as the standard bar, is a commercially available bar that is made of fiberglass and is approximately 33% lighter than the section of drill steel that is normally used for scaling. The second, referred to as the counterbalanced bar, was designed to bring the center of gravity of the bar as close to the operator as possible. This should reduce the external loading placed on the trunk while scaling. The third, referred to as the light bar, was constructed from aluminum tubing to be as light as possible. All bars used steel striking tips that screwed into the end. The relevant dimensions for the three bars are given in Table 6-1.

Subjects were provided with gloves, hardhats, and caplamps to be worn while performing the task. The caplamp was the only light available to the subject while performing the task. Knee pads were worn during conditions requiring kneeling postures.



Simulated Mine

FIGURE 6—1: SIMULATED MINE

TABLE 6-1

Scaling Bar Characteristics

BAR TYPE	LENGTH (cm.)	WEIGHT (kgs.)	CIRC. (cm.)	CG [from operators end (cm.)]
STANDARD	248	4.26	12.2	137.16
CTR-BAL	248	3.99	8.4	74.93
LIGHT	248	1.72	8.0	153.04

Standard = Commercially available scaling bar made of fiberglass; it is approx. 33% lighter than a similar length of drill steel (12.5 lb) that is normally used for scaling.

Ctr-bal = Counter-balanced scaling bar. Light = All-aluminum scaling bar.

Circ = Circumference CG = Center of gravity

Procedure

Subjects were brought into the laboratory and prepared for electromyographic (EMG) recording. The six muscles listed above were isolated and the skin prepared for electrode placement. At each electrode site, the skin was lightly abraded and conductive gel was applied. Two bipolar surface electrodes were placed on each muscle along its line of action 3 cm apart. Adequacy of skin preparation was checked by measuring the conductivity between the two electrodes. Values were checked for consistency in each pair between the left and right muscles. Electrode placement was verified using functional testing (static exertion) of each muscle sampled. Figure 6-2 shows the electrodes connected to small preamplifiers placed on a belt worn by the subject. Each preamplifier was connected to an amplifier after which the signal was rectified and integrated. The integrated signal was fed into an analog to digital converter and then sampled by the computer at a rate of 50 samples (for each channel) per second. Following completion of the exertion, the data were transferred from the computer's memory to the hard disk in the computer for storage. As shown in Figure 6-3, the integrated EMG signals were analyzed for the peak and mean values during the exertion period.

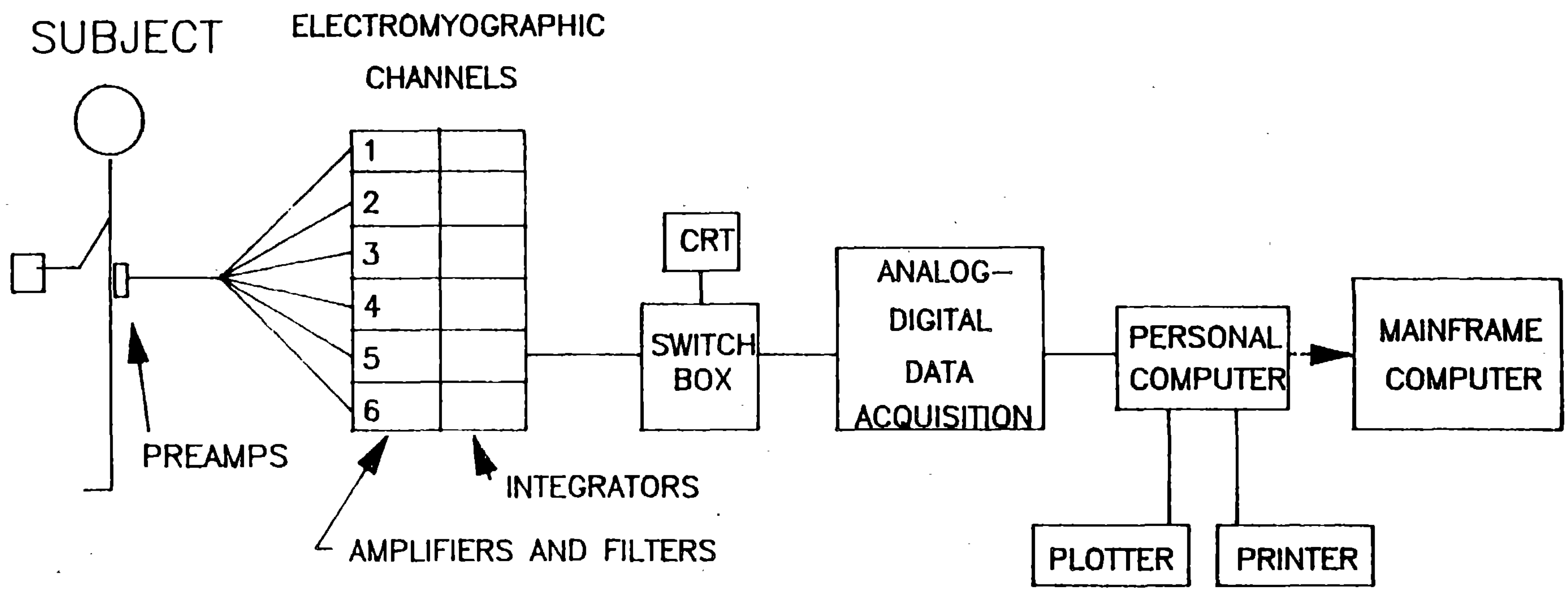
Before beginning the testing, the subjects were given practice sessions to become familiar with the scaling requirements. Subjects were instructed to perform a scaling task for 4 minutes in each experimental condition. The task required the subject to strike the dynamometer with the scaling bar and to follow with a prying motion. This is essentially how the tool is used underground. Each strike and pry cycle was initiated with an electronically generated tone every 6 seconds. Following each four-minute work period, the subject was given at least a four-minute rest period. Before each condition, the subject was instructed as to the method of tool use and the work posture. The peak upward and forward components of the strike force were recorded for each strike. EMG data were sampled on 3 random strikes for each condition.

Data Treatment

The mean EMG values were averaged within each condition and the largest peak value selected for analysis. For each muscle within each subject, EMG values were normalized with regard to the maximum and minimum values for that muscle with the following equation:

$$\text{Normalized EMG} = \frac{(\text{Task EMG} - \text{Min EMG})}{(\text{Max EMG} - \text{Min EMG})}$$

Maximum values were obtained through maximum voluntary contractions of the muscles measured in postures similar to those required in the task. Likewise, minimum values were measured in a relaxed standing posture.



DATA ACQUISITION SYSTEM

FIGURE 6–2: EMG DATA COLLECTION SYSTEM

MEASURES DERIVED FROM INTEGRATED EMG SIGNAL

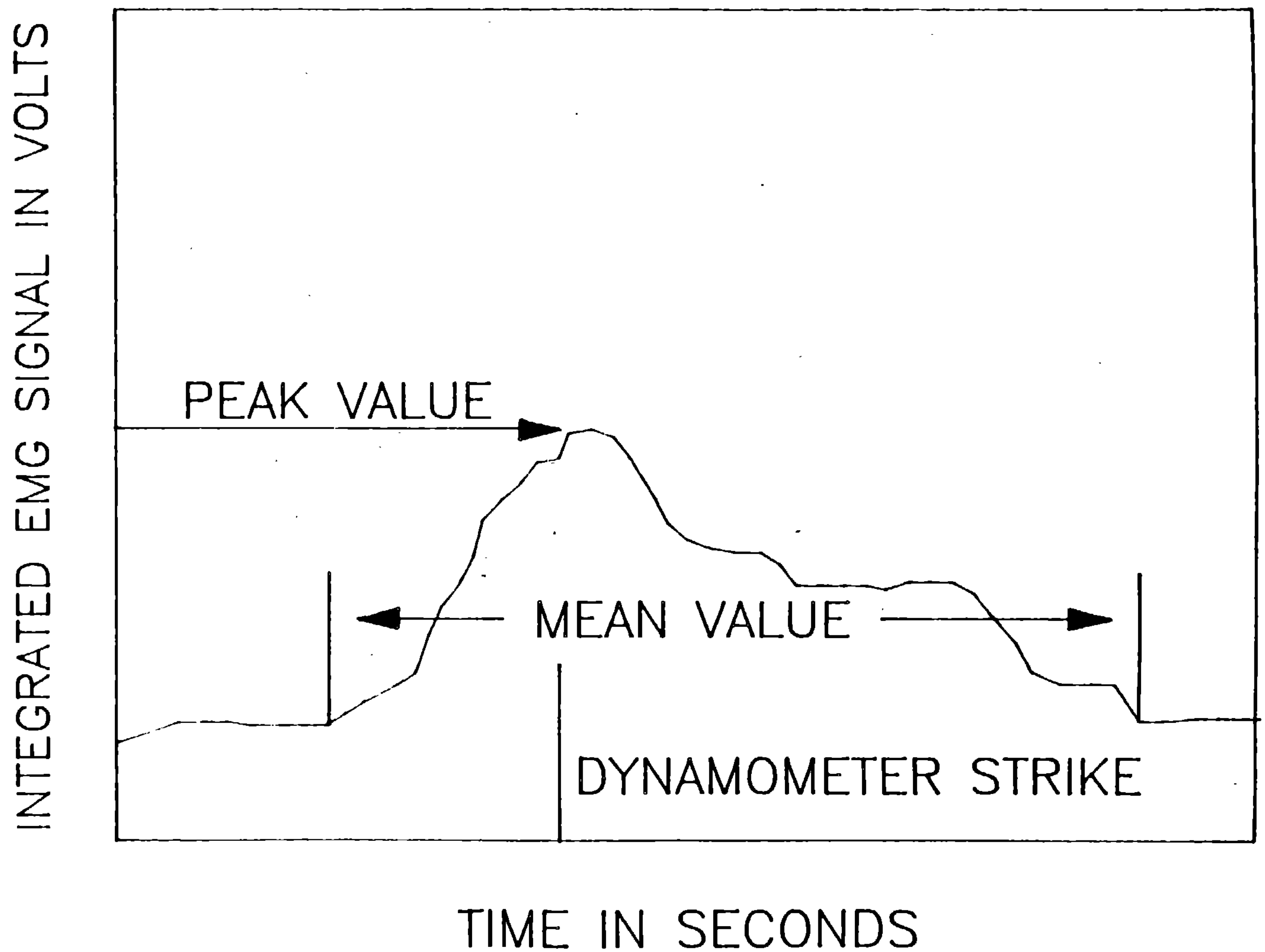


FIGURE 6–3: ANALYSIS OF INTEGRATED EMG SIGNAL

RESULTS

Separate analyses were conducted on the mean and peak normalized EMG values. In both cases, a MANOVA model including the EMG values from the six muscles was tested. The results of these tests are presented in Table 6-2. Both MANOVAs show the dependent measures to be under the control of the experimental manipulation. Since the design was blocked on subjects and roof height only, the bar-method interaction could be tested. This interaction was non-significant for the mean EMG model and for the peak EMG model. However, the MANOVAs showed all main effects were highly significant. Subsequent ANOVAs for each dependent measure were conducted to evaluate which muscles were affected by the manipulations. These were evaluated using an adjusted alpha level (Bon Feroni procedure) of .00833. Dependent measures that showed significant differences are presented in Table 6-3. All dependent measures showed a significant subject effect which is not reported here. Individual differences in activation of muscles would account for these results.

All bar effects shown in figures 6-4e and 6-4f when tested with a Duncan's multiple comparison procedure show the standard bar to require greater muscular force than either the counterbalanced bar or the lightweight aluminum bar. This was true for the right erector spinae muscle and the left and right latissimus dorsi muscles. Tests comparing the resultant strike force by the three types of bars showed no significant differences. The trend showed the standard bar had the highest strike force, followed closely by the counterbalanced bar, with the light aluminum bar having the lowest strike values. Only the mean activity in the left latissimus dorsi muscle showed a significant increase with the overhand method (fig. 6-4a). However, subjects typically complained of muscle fatigue when using this method of scaling.

Changes in roof height conditions differentially affected the muscular force required from the latissimus dorsi muscles, the left erector spinae muscle, and the right abdominal muscle. Higher roof heights generated significantly more latissimus dorsi and right abdominal activation, while the low roof conditions generated significantly more activity in the left erector spinae. These changes may reflect differences in trunk stabilization patterns in the standing versus the kneeling postures.

The EMG activities were used as input to the SIMULIFT dynamic biomechanical model developed by Reilly and Marras (1987). This model was used to study the compressive and shear forces acting on the spine as a function of the experimental variables. The peak compression and shear forces acting on the lumbar spine were tested for statistical significance between the experimental conditions. The results of this analysis are shown in table 6-4. This table indicates that a significant change in peak spine compression occurs due to both bar and roof height effects. No statistically significant differences in compression due to method or the bar and method interaction were noted.

TABLE 6–2

MANOVA RESULTS

ANALYSIS OF MEAN EMG DATA			ANALYSIS OF PEAK EMG DATA		
TEST	F (WILKS')	PROBABILITY	TEST	F (WILKS')	PROBABILITY
Subject	10.91	p=0.0001	Subject	9.95	p=0.0001
Roof	24.88	p=0.0001	Roof	14.24	p=0.0001
Method	4.38	p=0.0004	Method	2.05	p=0.0628
Bar	4.19	p=0.0001	Bar	3.34	p=0.0001
Method*Bar	0.63	ns	Method*Bar	0.75	ns

Table 6–3

SIGNIFICANT ANOVA'S USING MEAN EMG VALUES				SIGNIFICANT ANOVA'S USING PEAK EMG VALUES			
DV	TEST	F (WILKS')	PROBABILITY	DV	TEST	F (WILKS')	PROBABILITY
LATR	BAR	16.78	0.0001	LATR	BAR	12.21	0.0001
LATL	ROOF	36.00	0.0001	LATL	ROOF	12.20	0.0006
	METHOD	15.11	0.0002		BAR	8.17	0.0004
	BAR	9.20	0.0002				
ERSR	BAR	8.43	0.0003	ERSR	BAR	5.93	0.0033
ERSL	ROOF	66.48	0.0001	ERSL	ROOF	32.96	0.0001
RCAR	ROOF	8.13	0.0050				

DV = Dependent variable
LATR = Right latissimus dorsi muscle
LATL = Left latissimus dorsi muscle
ERSR = Right erector spinae muscle
ERSL = Left erector spinae muscle
RCAR = Right rectus abdominus muscle

MEAN MUSCLE EMG AS A FUNCTION OF METHOD

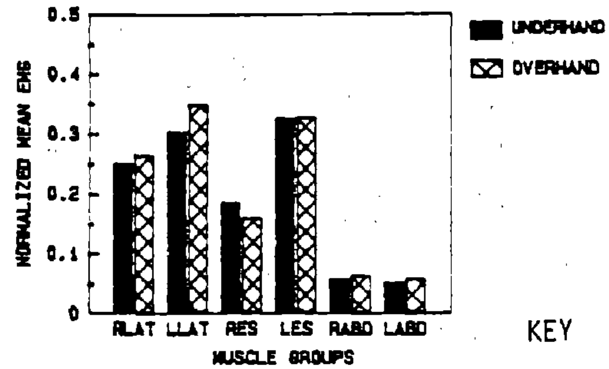


Fig. 6–4a

PEAK MUSCLE EMG AS A FUNCTION OF METHOD

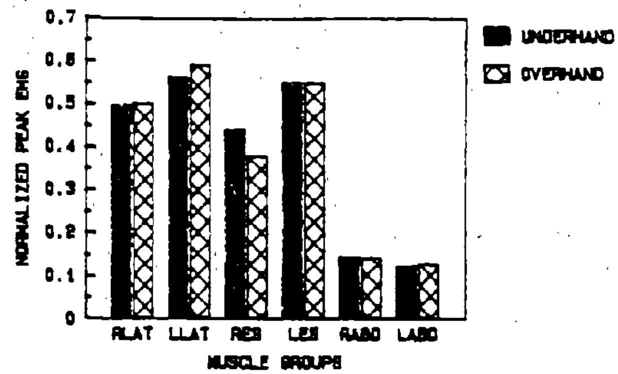


Fig. 6–4b

KEY

RLAT = Right latissimus dorsi muscle

LLAT = Left latissimus dorsi muscle

MEAN MUSCLE EMG AS A FUNCTION OF ROOF HEIGHT

Fig. 6–4c

PEAK MUSCLE EMG AS A FUNCTION OF ROOF HEIGHT

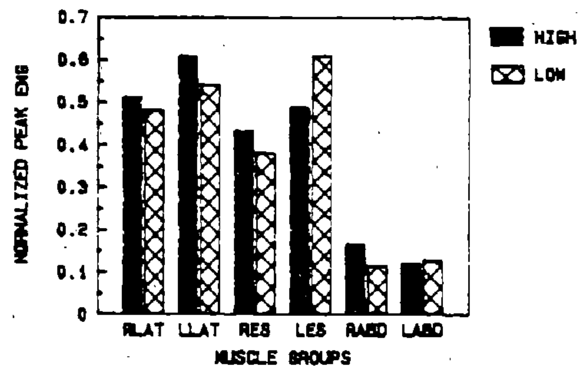


Fig. 6–4d

KEY

RES = Right erector spinae muscle

LES = Left erector spinae muscle

MEAN MUSCLE EMG AS A FUNCTION OF BAR TYPE

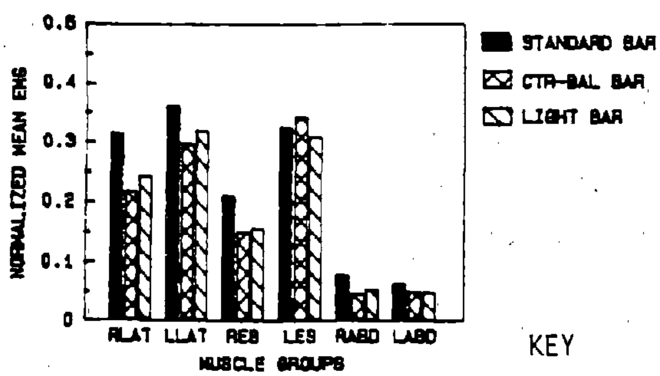


Fig. 6–4e

PEAK MUSCLE EMG AS A FUNCTION OF BAR TYPE

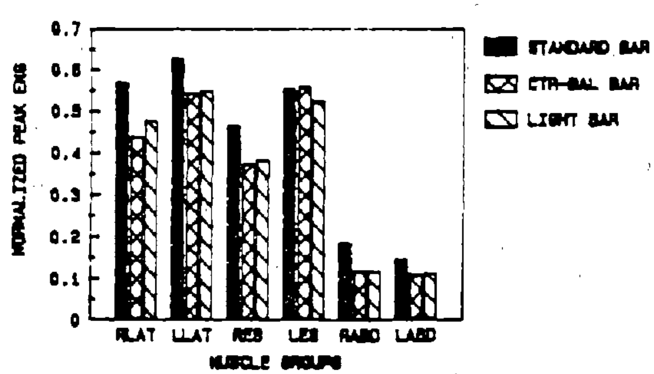


Fig. 6–4f

KEY

RABD = Right rectus abdominus muscle

LABD = Left rectus abdominus muscle

TABLE 6–4

STATISTICAL TEST OF ESTIMATED COMPRESSION AND SHEAR FORCES ON THE SPINE

INDEPENDENT VARIABLE	COMPRESS TEST PROBABILITY	SHEAR TEST PROBABILITY
SUBJECT	$p<0.0001$	$p<0.0001$
BAR	$p<0.0025$	$p<0.0005$
ROOF	$p<0.055$	ns
METHOD	ns	ns
BAR*METHOD	ns	ns

Differences in compression due to bar type are shown in figure 6-5. This figure shows that both the light bar and the counterbalanced bar produced lower amounts of spine compression than the standard bar. Figure 6-6 indicates the effect of roof height upon compression. This figure indicates that low roof condition results in approximately a 150 N (33.7 lb) increase in compression. Table 6-4 indicates that the shear forces acting on the spine change as a function of the type of bar only. The trend in shear forces is shown in Figure 6-7. The counter-balanced bar produces less shear than either the standard or the light bar.

The peak dynamometer strike forces are shown in Figure 6-8. Even though these results are not significantly different, it is clear that the standard bar and the counterbalanced bar produce greater amounts of force. It is interesting to note that the tool forces are comparable between the standard and the counterbalanced bars, and the spine forces are lowered with the light and counterbalanced bar. Thus, the cost of doing work (to the spine) is lower when the nonstandard bars are used to perform the scaling task.

DISCUSSION

The results described above illustrate the effects of bar type, roof height, and scaling method on the muscular force required to perform the scaling task used in this study. The effects of method were least salient with the exception of the left latissimus dorsi. This is not surprising since the difference in the two methods focuses on the posture of the left arm during the scaling task. Abduction of the left shoulder would generate a larger external moment to be counteracted by the musculature. As mentioned above, the overhand method was not preferred by our subjects who typically complained of fatigue in the shoulder muscles following sessions employing the method. This method is thought to protect miners from debris sliding down the bar. Most miners interviewed underground expressed that this was not a frequent problem.

The elevation in muscular activity in the left erector spinae with lower roof heights is thought to represent the increased moment about the spine due to increased trunk flexion in this posture. This is consistent with the increased erector spinae activity reported by Gallagher (1987) when investigating the physiological demands of the kneeling work posture. In both postures, the required motion was asymmetric as shown in the elevated activity of the left latisimus dorsi and left erector spinae musculature relative to the corresponding right musculature. However, when in a kneeling posture, subjects are forced to make even more of an asymmetric motion with the torso since no twisting motion can occur at or below the pelvic level. The increase in the left erector spinae and possibly the slight decrease in the right erector spinae can be attributed to this motion. In the standing posture, the load tends to be compensated for with the latissimus dorsi muscles, possibly the right erector spinae, and likely some motion in the pelvis.

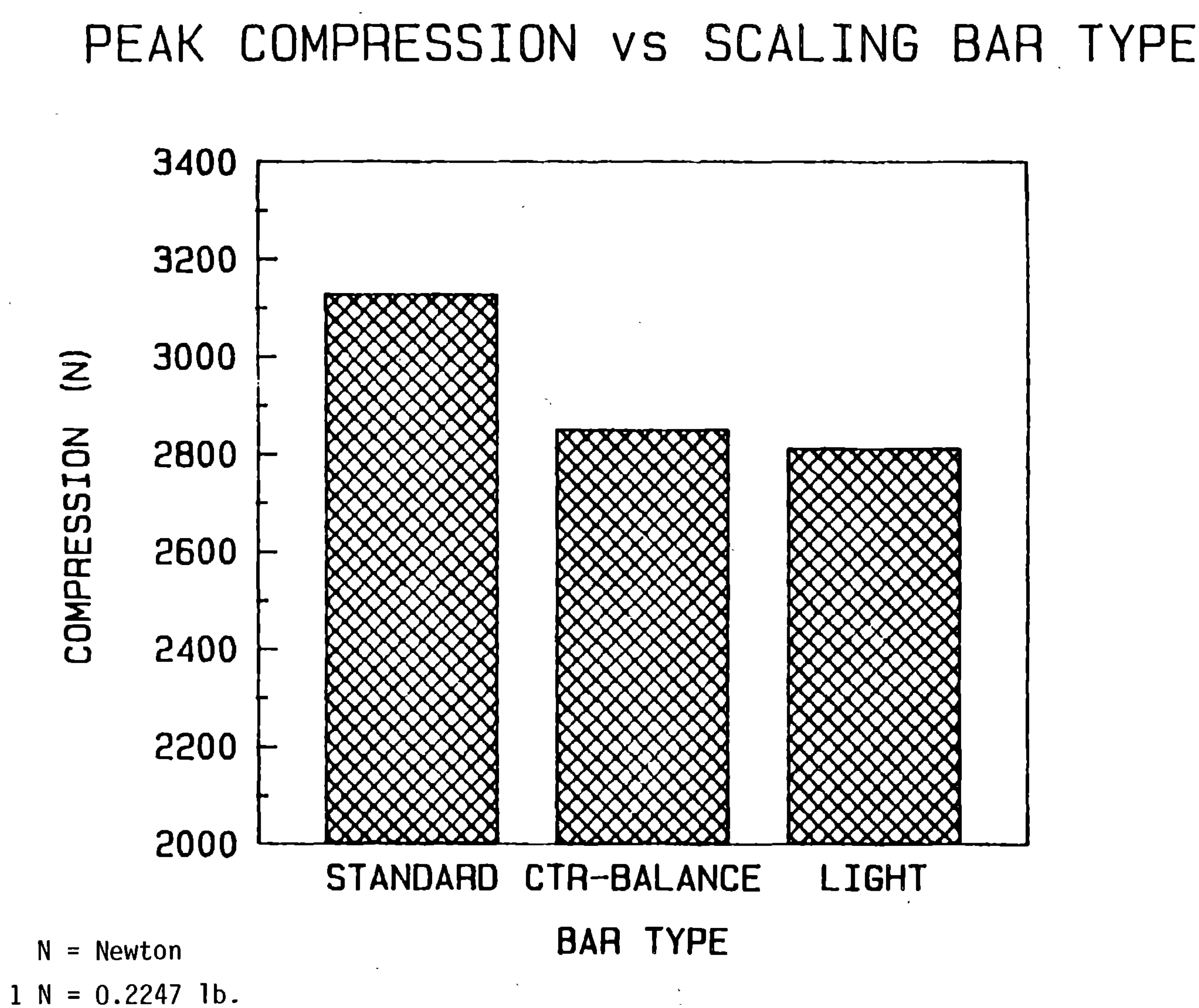


FIGURE 6—5: PEAK COMPRESSION AS A FUNCTION OF BAR TYPE

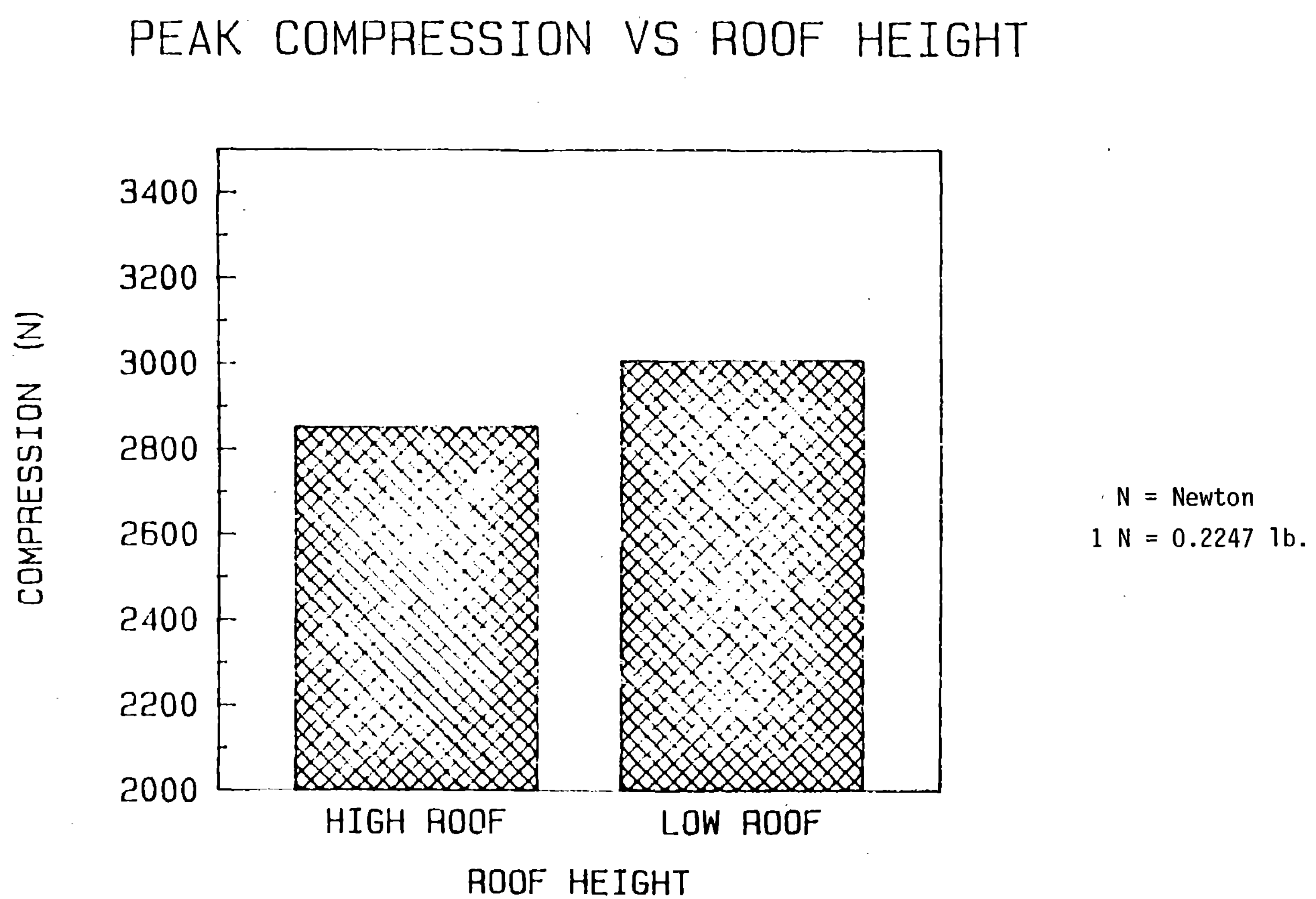


FIGURE 6—6: PEAK COMPRESSION AS A FUNCTION OF ROOF HEIGHT

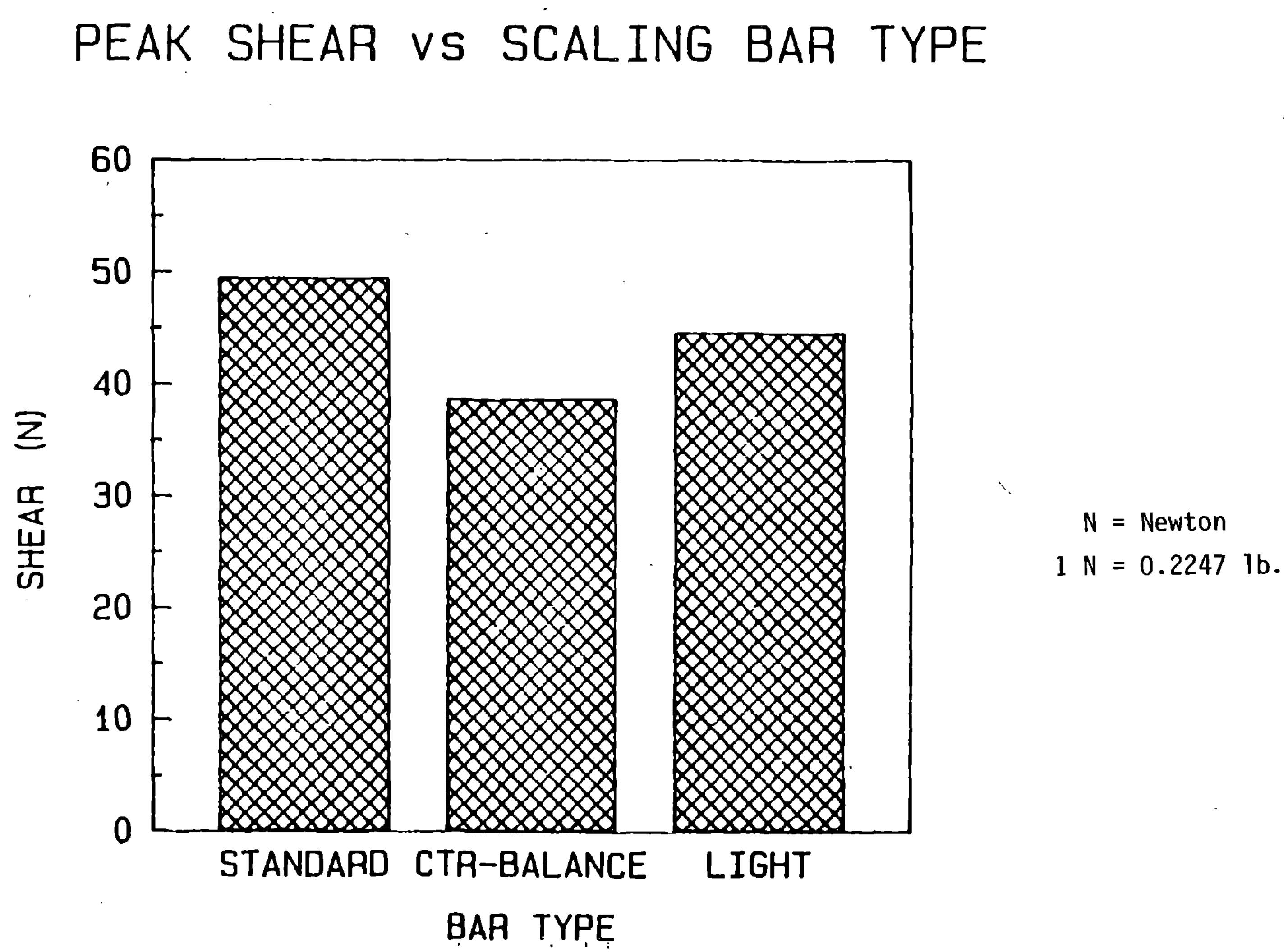


FIGURE 6—7: PEAK SHEAR AS A FUNCTION OF BAR TYPE

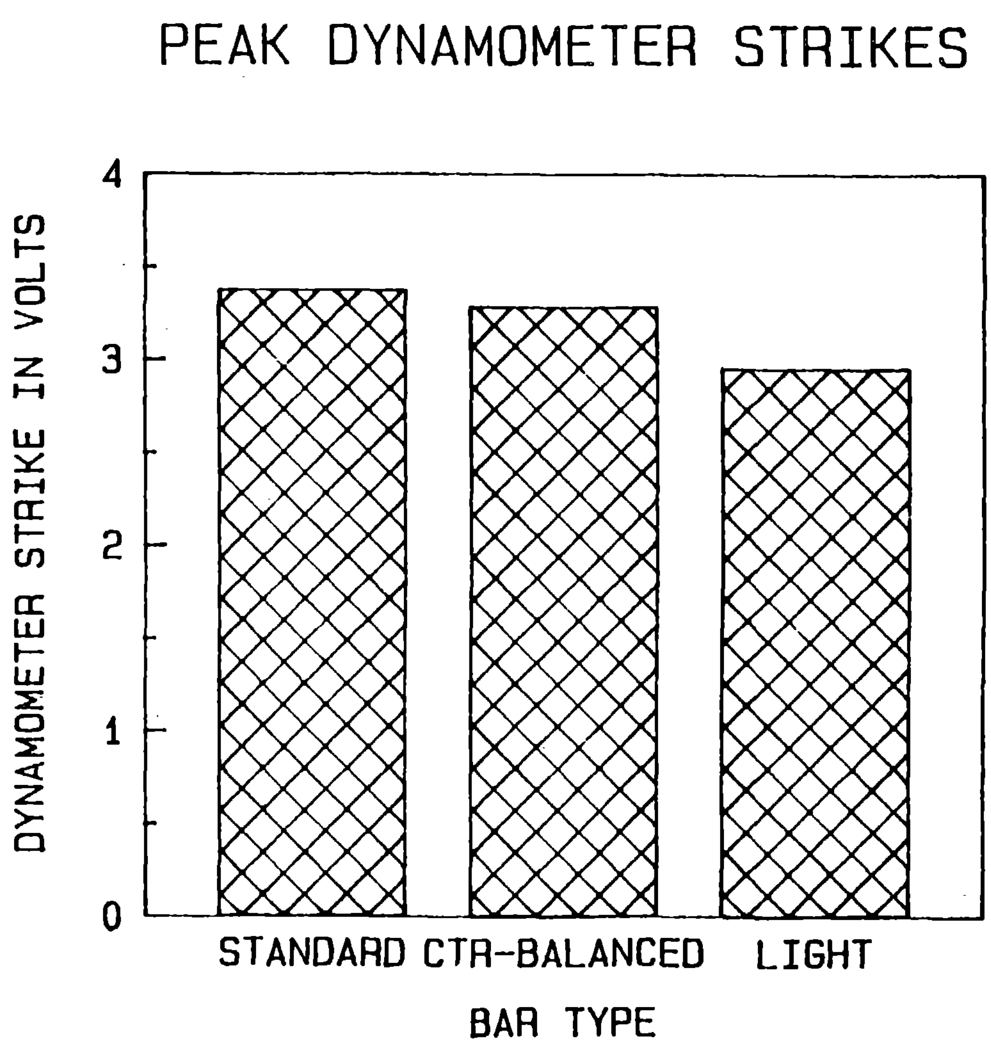


FIGURE 6-8: PEAK DYNAMOMETER STRIKE FORCES

The lack of a significant difference in the strike force imparted by the 3 types of bars, along with the reduced muscle activity seen in the light and counterbalanced bars, suggest the importance of bar design. The most frequently observed bars in our visits underground were old drill steel. The weight of a bar constructed of this material and of similar length to those used here would exceed that of our standard bar (made of fiberglass) by 33%. The results of the present study indicate that the weight of the bar is not necessarily a determinant of its effectiveness. Hence, lighter bars, possibly counterbalanced would maintain effective scaling and would bring the external load closer to the spine. This would decrease the moment arm and therefore the compressive forces acting on the spine. Following the experiment, subjects gave the counterbalanced bar the most favorable evaluation, thereby suggesting this as a direction for further investigation of scaling bar design.

The biomechanical evaluation of spine loadings also confirms this logic. The predicted spine force analyses indicated that the counterbalanced and light bars produced the least amount of force on the spine. This is particularly significant when considered in conjunction with the fact that there is little difference in the amount of force one can generate using the various tool designs. Thus, these biomechanical analyses indicate that the use of alternative scaling bar designs in the workplace can significantly reduce the risk of a low-back disorder due to cumulative trauma. This is of utmost importance since it is believed that it is the repetitive wear and tear upon the spine (cumulative trauma) that poses the largest risk of injury. Reduction of spine forces by even a small amount (i.e. 150 N due to spine compression) can result in a substantial savings in spine wear and tear when the daily, monthly, and yearly frequency of scaling bar use is considered.

CHAPTER 7: JACKLEG DRILL EXPERIMENT

INTRODUCTION

The epidemiological analysis has revealed that the jackleg drill is a tool that deserves further attention. Over the six-year period from 1978 to 1983, the jackleg drill was associated with over 44% of all hand tool accidents in metal-nonmetal mining. An examination of the injury component sequences revealed that both exertion and struck-by components were common during the use of this tool. It is suggested that many of the struck-by accidents may be controlled through better illumination of the workplace. However, there is no "quick fix" solution to the exertion injuries.

Observations of tool use and discussions with the workers revealed that the tool was very heavy, awkward, and required substantial strength to manipulate and operate. The task analysis identified 11 elements in the use of the drill. When the ergonomic analysis was performed, several of these elements were identified as areas of biomechanical concern for the drilling portion of the jackleg drill use task. It was hypothesized that the addition of a handle on the drill would ameliorate the situation when the operator was working at different hole height levels. The task and ergonomic analyses also suggested that the benefits of a handle would depend on the task element. The positioning, collaring, and removal elements were identified as elements that might benefit from a handle.

The analyses also revealed that the carrying element of tool use might also be involved in injury risk. The typical carrying task involved picking up the drill, transporting the drill, stepping over obstacles, turning, and putting down the drill. The hypotheses suggest that the addition of a handle on the tool would also reduce the risk of injury in the carrying task.

Since the objective of this experiment was to assess the risk of exertion injuries to the back, the internal forces within the trunk were considered as the dependent measures. Previous research has demonstrated that the main internal forces that load the back during work are the result of muscular activity. In the present study, the status of the muscles within the trunk were monitored via electromyography (EMG). Muscle selection was accomplished via the transverse plane analysis technique suggested by Schultz and Andersson (1981). This technique assumes that if an imaginary transverse plane were passed through the trunk, the internal structures that support and load the spine would be identifiable (along the plane). In this study, the erector spinae, latissimus dorsi, and rectus abdominus muscles were identified along this transverse plane as the main trunk-loading internal forces. Through proper conditioning of the EMG signal, the force present within the muscle can be estimated. This information can also be used as input to spine-loading models.

METHODS

Experiment 1

The first procedure was used to test three tasks, performed while operating the jackleg drill, that were identified as strenuous to the lower back. These were the orientation of the drill, collaring or starting a new hole with the drill, and the removal of the drill when the hole is completed. All tasks were performed with and without an additional handle mounted on the drill casing. This handle was hypothesized to reduce loadings on the spine, as measured with EMG, while performing selected tasks. In addition, each task was performed at three levels of hole height.

The experiment was designed to investigate the change in the internal forces as a function of the task, the height at which the task was performed, and the presence of an additional handle. These internal forces were evaluated using the peak and mean EMG levels from six muscles whose primary job is trunk stabilization. These muscles were the left and right latissimus dorsi, the left and right erector spinae, and the left and right rectus abdominus.

Subjects

This study used 8 male volunteer subjects who were novices with respect to jackleg drill operation. Subjects received training in handling and operating techniques typically used by miners. Each subject attended between one and three training sessions prior to testing, depending on their ability to effectively perform the task. All subjects were between the ages of 23 and 39. The mean height and weight were 187.34 cm (s = 6.30 cm) and 88.25 kg (s = 11.17 kg). None of the subjects reported any prior incidence of low-back pain.

Experimental Design

This experiment was designed to test drill positioning and drill removal during the presence and absence of an additional handle, at three levels of work height. In addition, the experiment evaluated a third task, collaring, at the three levels of hole height. Due to time constraints involved with mounting and removing the handle, the handle variable served as a blocking factor. The ordering of the two handle conditions was counterbalanced with 4 subjects participating in the handle block first, and 4 subjects participating in the no-handle block first. Within each handle condition, the order of each task was randomized; within each task, the order of the hole height conditions was randomized. The experiment was a repeated-measures design where each subject participated in each cell of the experimental design. Within each cell, two trials were conducted. Data from the two trials were averaged before undergoing statistical analysis.

Apparatus

A simulated underground mine was constructed to mimic the conditions typical of the underground work environment. The key features of this laboratory simulation are shown in Figure 6-1. The work area was 3.7 m long and 1.5 m wide. The roof was 2.7 m above the 10 cm thick loose gravel floor. At the front of the work area was the simulated "rock face" constructed from wood. The rock face was 8.9 cm thick and as wide and as high as the work space just described. Two holes were drilled at each of the three specified heights in the rock face. One set of 3 holes was filled with pipe caps to simulate the positioning and collaring tasks. These hole heights were 53, 118, and 205 cm. The other set of 3 holes were drilled completely through the face to test the drill removal task. These hole heights were at 53, 118, 237 cm. The only lighting in the work area was from the caplamp worn by the subject. All subjects were issued hearing protection and were given gloves to wear while performing the experimental tasks.

The jackleg drill used in the experiment was manufactured by Ingersol-Rand (see note below) and weighed 52.2 kg. The tool was powered by means of an air compressor parked outside the room. A 5-cm diameter air line connected the drill with the compressor. There were two controls on the drill that the subject was required to operate (see Figure 7-1). The first was the feedleg extension control. This control was made to be gripped by the operator's right hand and was mounted on the rear handle of the drill casing. The second control was the throttle control which was operated with the left hand.

Mounted on the feedleg of the drill was a handle, generally referred to as the "D" handle. The D handle is typically used when carrying the drill short distances. An additional handle was fabricated from hickory and aluminium that could be mounted and removed within a short period of time. Figure 7-1 shows this handle and its orientation with respect to the drill casing and the operator. The anchor point of the feedleg on the floor was controlled and constant for all subjects. The fork at the end of the leg was hooked over a steel bar that prevented the leg from sliding when air pressure was applied.

Two lengths of drill steel were used. The 70 cm steel was used when testing the low and medium holes, while the 132 cm steel was used when testing the highest holes.

<u>Procedure</u>

Subjects were brought into the laboratory and prepared for electromyographic (EMG) recording. The six muscles listed above were isolated and the skin prepared for electrode placement. At each electrode site, the skin was lightly abraded and conductive gel was applied. Two bipolar surface electrodes were placed on each muscle along its line of action 3 cm apart. Adequacy of skin preparation was checked by measuring the conductivity between the two electrodes. Values were checked for consistency in each pair between the left and right muscles. Electrode placement was verified using functional testing (static exertion) of each muscle sampled. Figure 6-2 shows the electrodes connected to small preamplifiers placed on a belt worn by the subject. Each preamplifier was connected to an amplifier after which the signal was rectified and integrated. The integrated signal was fed into an analog to digital converter and then sampled by the computer at a rate of 50

Note: Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

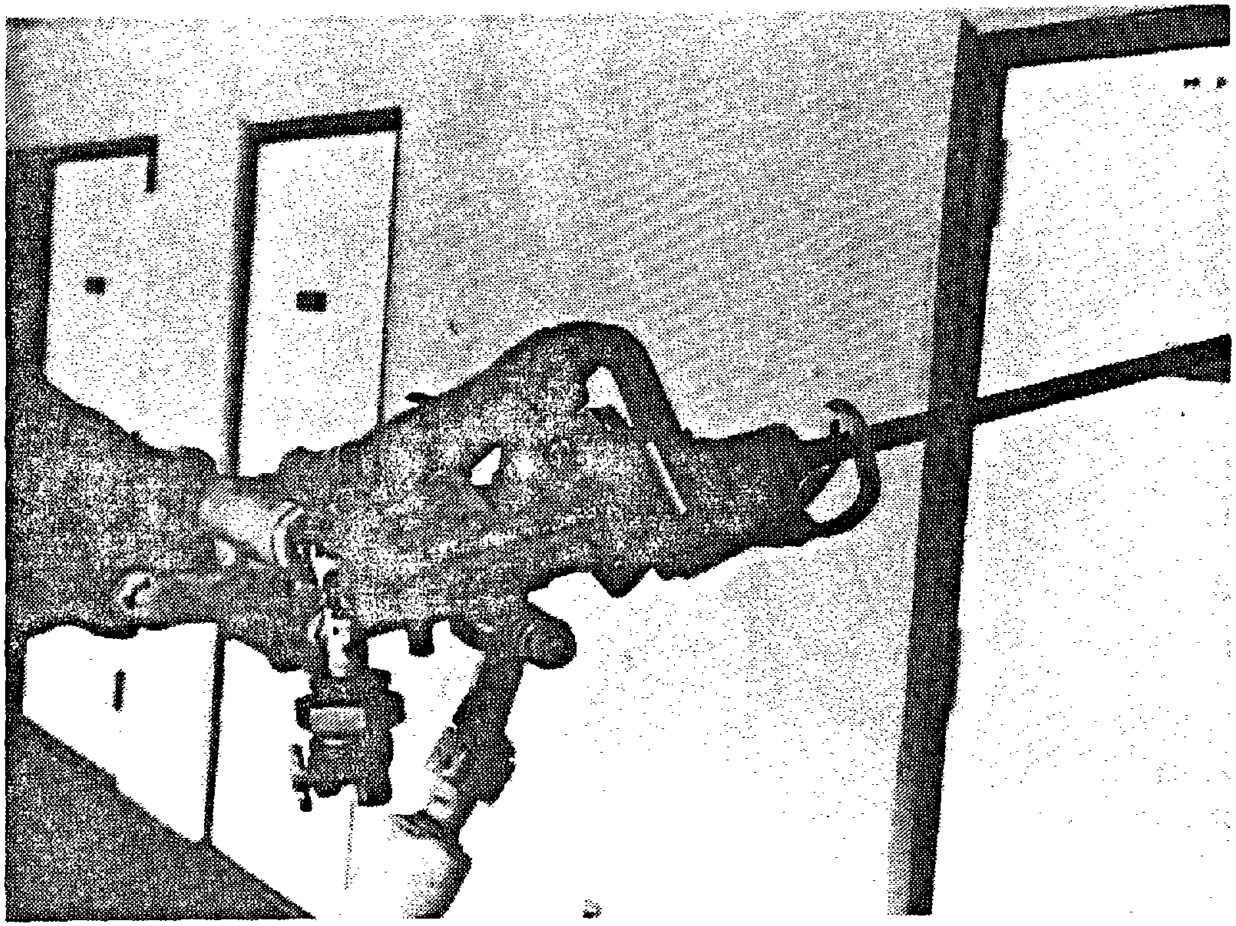


FIGURE 7—1: Experimental handle mounted on the jackleg drill

samples (for each channel) per second. Following completion of the exertion, the data were transferred from the computer's memory to the hard disk in the computer for storage. As shown in Figure 6-3, the signals were analyzed for the peak and mean values during the exertion period.

Each subject's data collection session began with tests of maximal static exertions in postures similar to those required by the tasks. The peak values collected here were used in normalizing the EMG data for each subject. Following tests for maximal exertions, tests using the three experimental tasks were conducted. Whether the handle was present or not was determined by the counterbalancing procedure. The tasks will be described not necessarily in the order presented since their order was randomized for each subject.

The positioning task required the subject to orient and place the drill steel in one of the three selected pipecaps mounted in the "rock" face. The order of the caps was selected using a random number generator. The task began with the drill in what will be called the leg vertical position. This is when the leg of the drill is vertical, not extended, and the drill is oriented horizontally. While orienting the drill, the subject was instructed to use the leg extension control where appropriate. If the subject was unable to place the steel either on the first attempt or after one corrective action, the trial was discontinued.

Upon placement of the steel in the pipecap, the subjects were instructed to turn the throttle on low to simulate the collaring task. The collaring task was performed for 3 seconds after which the subject returned the drill to the leg vertical position. EMG data collection was initiated 1 second prior to the start signal given to subject. The data were collected continuously until the collaring task was completed. When the subject turned on the drill throttle, the experimenter pressed a switch to mark in the EMG data where the orienting task ended and the collaring began. Each trial was repeated twice before proceeding to the next cell of the experimental design. In between each trial, the subject was given a 2-minute rest period.

The drill removal task was set up with the drill steel inserted in one of the three holes (53 cm, 118 cm, or 237 cm) in the rock face up to the steel retainer on the drill casing. The subject was instructed to remove the drill from the face and return it to the leg vertical position. EMG data were collected from 1 second prior to the exertion until the exertion was completed (approximately 3 to 5 seconds). Again, two trials were conducted at each hole height. Following the completion of the three tasks, the subject was given a 15-minute break while the experimental handle was either removed from or mounted on the drill casing. Then the above procedure was repeated for the second block of trials.

Experiment II

The second experiment investigated the internal forces generated while carrying the jackleg drill as a function of an additional handle mounted on the drill casing and the nature of the carrying task. It was hypothesized that the presence of a handle on top of the drill casing would aid in redistributing the load to be more sagitally symmetric. Non-sagitally symmetric (asymmetric) loading increases the shear components during spinal loading. High shear components have been suggested as a likely causal agent in the development of low back disorders (Lavender et al., accepted for publication). The following experiment investigated the change in internal forces due to the types of carrying tasks performed. While carrying the drill, subjects were asked, in addition to stepping over obstacles, to pick up the drill, pivot 180°, and to replace the drill in its starting position.

Subjects

The eight subjects who participated in the scaling bar experiment were also recruited for the present study. Subjects were compensated with an Ohio State Biodynamics Laboratory T-shirt for their efforts.

Experimental Design

The experiment investigated two handle conditions; specifically, whether the handle was present or not. Four subtasks were sampled during the carrying task. These were lifting the drill from its initial position of leaning against the face, transporting the drill over obstacles, turning 180° with the drill, and replacing the drill in its initial position.

The internal forces measured during these exertions were from the left and right latissimus dorsi (LATL and LATR), the left and right erector spinae (ERSL and ERSR), and the left and right rectus abdominus (RABL and RABR). Again, the peak and mean EMG signals during the selected periods were used in the data analysis.

Apparatus

The experiment was carried out in the simulated mine environment described above, and with the same jackleg drill. An obstacle 20 cm high was placed in the subjects path to simulate the cluttered floor conditions observed underground. A red line painted on the gravel served as the marker at which the subject was to turn around.

The additional handle used in this experiment is the same handle described above and pictured in Figure 7-1. Likewise, the data collection system described in the scaling bar experiment was also used in this study.

Procedure

Subjects were prepared for EMG data collection as previously described. The experimental task required the subjects to pick up the drill from its position leaning against the face, walk the length of the mine simulator (stepping over the obstacle), turn 180°, walk the length of the simulator (again stepping over the obstacle), and replace the drill in its initial position.

Subjects were instructed, in the handle condition, to pick up and carry the drill with the experimental handle in the left hand, and the "D" handle in the right hand. In the absence of the experimental handle, subjects were instructed to cradle the drill body in their left arm and grasp the "D" handle with their right hand. Subjects were instructed to pause 1 second after picking up the drill and also following the 180° turn.

EMG data were collected from 1 second before the task was initiated until the drill was replaced. The experimenter used a marker switch to indicate where each event in the experimental procedure occurred. Two trials were collected for each of the two handle conditions for each subject.

RESULTS

Experiment 1

The multivariate and univariate statistical summaries for the jackleg drill (JLD) positioning tasks are presented in Table 7-1. This table indicates a statistically significant multivariate effect for both the mean and peak trunk muscle responses to both handle and hole height conditions, as well as a significant subject effect. Univariate analysis of variance (ANOVA) procedures were used as follow-up procedures for the effects that were found to be significant according to the multivariate analysis of variance (MANOVA) tests. These ANOVA tests indicated that the right rectus abdominus muscle was responsible for the handle effect significance. Post hoc tests indicated that this muscle was significantly more active when the handle was attached to the drill compared to the no-handle condition. This was the only muscle that exhibited a significant reaction to the handle condition.

When hole height was considered, the ANOVA tests indicated that both the right and left erector spinae muscles displayed significant differences in mean activity in response to the hole height conditions. The responses of the trunk muscles are shown in Figure 7-2. This figure and the post hoc tests indicate that for both the right and left erector spinae muscles the activity is significantly less under the high hole conditions.

Both handle and hole height effects were found to be significant via the MANOVA evaluation when the peak muscle activities were considered. Peak muscle responses to handle conditions during positioning are shown in Figure 7-3. The ANOVA follow-up analyses indicated that the right rectus abdominus muscle was significant for the handle effect. The trend in this case indicated that increased activity occurred when a handle was present on the drill. Peak muscle responses to hole height conditions during positioning are shown in Figure 7-4. The right latissimus dorsi muscle was the only muscle that displayed a significant F value in the ANOVA analysis when hole height was considered. This muscle displayed increased peak muscle activity while positioning the drill at the low and high holes compared with the medium-height hole.

The statistical summary of the mean and peak trunk muscle activities for the JLD collaring task is shown in Table 7-2. This table shows a significant subject and hole height effect for the mean trunk muscle activities. The nature of the trunk muscle responses are shown in Figure 7-5 for the various hole height conditions. ANOVA analyses of these responses indicate that the right and left latissimus dorsi muscles, the right erector spinae muscle, and the right and left abdominal muscles all responded differently to the various hole height conditions. Figure 7-5 and post hoc analyses indicate that for the latissimus muscles the activity increases as the hole height increases.

However, in the case of the left erector spinae muscle, there was no statistically significant difference in response between the low and medium height holes. The right erector spinae muscle exhibited significantly greater activity in the low hole position compared to the medium or high hole conditions. Finally, the rectus abdominus muscles exhibited significantly greater activity at the medium and high hole conditions compared with the low hole condition.

Table 7-2 also shows the statistical summary of the peak muscle activities for the collaring task. As with the mean muscle activities, the MANOVA analysis indicates that there are significant subject and hole effects in the collective response of the trunk muscles. The peak muscle activities as a function of hole height for the collaring task are shown in Figure 7-6.

The ANOVA and post hoc tests indicate that the MANOVA significance was due to the activity of the right and left latissimus dorsi muscles, the right and left erector spinae muscles, and right rectus abdominus muscle. The trend for the latissimus dorsi muscles indicated that muscle activity at the high hole was significantly greater than at the medium or low holes. The right erector spinae muscle showed significantly greater activity while collaring in the low hole. Also, the right abdominal muscle displayed greater activity at the medium and high holes compared to the low hole. However, the general trend indicated that the muscle activity increased as hole height increased.

The mean and peak muscle activity statistical significance summary for the JLD removal task is shown in Table 7-3. This summary indicates that significant multivariate effects due to the subject, handle, and hole height are present when mean trunk muscle activity is considered. The ANOVA analysis showed that no single muscle response was responsible for the significant multivariate reaction to handle effects. The muscle responses during drill removal are shown in Figure 7-7 as a function of hole height. The ANOVA summaries indicated that the right latissimus dorsi and left erector spinae muscles both exhibited significantly different responses to the hole height conditions. The latissimus dorsi muscle showed the greatest response to the high hole condition when compared to the low and medium hole conditions. The erector spinae muscle did not exhibit any significantly different responses between the low and medium height holes; however, the responses to both of these conditions was significantly greater than for the high hole condition.

Table 7-3 also indicates that there are no significant multivariate or univariate effects to the handle or hole height conditions or to their interaction when the peak muscle activities are considered.

The continuous muscle responses were also used to predict peak spine compression and shear forces. The SIMULIFT biomechanical model developed by Reilly and Marras (1987) was used to predict these impulse forces on the spine. Figures 7-8 through 7-13 show the compression and shear predictions for the JLD positioning, collaring, and removal tasks, respectively. The scale on the right hand side of the compression plots indicates the risk of vertebral endplate microfracture based upon values presented in the Work Practices Guide for Manual Lifting (NIOSH, 1981). These analyses indicate that the positioning and removal tasks involve a particularly significant risk of spine overload. No such comparisons are available for the shear forces at this time.

Table 7-4 summarizes the statistically significant differences in compression and shear due to the the various experimental treatments during the various JLD use tasks. This table and the associated figures indicate that for the positioning task, spine compression increases as hole height decreases. Figure 7-8 shows that a risk of vertebral endplate microfracture exists for all hole height conditions. The risk is greatest (about 4 percent) for the low hole condition when the handle is used. Interestingly, in the high hole condition, the risk can be substantially reduced by not using the handle; whereas in the medium hole condition, spine compression is less when the handle is used. The shear estimates for the various positioning components (Figure 7-9) are low and not significantly different between conditions. It must be pointed out that no shear risk values are available; therefore, it is difficult to make an absolute judgement about the risk due to shear forces for the various JLD tasks.

Figures 7-10 and 7-11 show the compression and shear predictions for the various components of the collaring task. These figures and Table 7-4 indicate that the compression and shear values for the collaring task are both low and not significantly different between conditions. Figure 7-10 indicates that for all hole height conditions, the spine compression is below the level at which one would expect vertebral endplate fracture to occur.

The compression and shear predictions for the removal task are shown in Figures 7-12 and 7-13, respectively. Figure 7-12 shows that the compression risk varies from 4 to 20 percent as a function of the experimental conditions. Table 7-4 shows a significant hole height difference and handle-hole height interaction. The low and medium height holes result in greater compression values than does the high hole. Figure 7-14 shows the nature of the interaction. This figure indicates that spine compression can be substantially reduced (600N) at the low hole condition by providing the operator with a handle. However, for the medium and high holes the inclusion of a handle would increase compression by about 200N. The spine shear for drill removal is shown in Figure 7-13. This figure and Table 7-4 indicate that low shear levels are present and there is no statistically significant difference between conditions.

TABLE 7–1

TASK: POSITIONING

MEANS		PEAKS	
MANOVA EFFECTS:		**MANOVA EFFECTS:**	
SUBJECT	$P < 0.0001$	SUBJECT	$P < 0.0001$
HANDLE	$P < 0.03$	HANDLE	$P < 0.05$
HOLE HEIGHT	$P < 0.002$	HOLE HEIGHT	$P < 0.05$
HANDLE * HOLE HEIGHT	NS	HANDLE * HOLE HEIGHT	NS
FOLLOW UP ANOVAS:		**FOLLOW UP ANOVAS:**	
MUSCLES SHOWING SIGNIFICANT HANDLE EFFECTS:		MUSCLES SHOWING SIGNIFICANT HANDLE EFFECTS	
RABR	$P < 0.0015$ (Handle > No Handle)	RABR	$P < 0.007$ (Handle > No Handle)
MUSCLES SHOWING SIGNIFICANT HOLE HEIGHT EFFECTS:		MUSCLES SHOWING SIGNIFICANT HOLE HEIGHT EFFECTS:	
ERSR	$P < 0.0001$ (Low = Med) > High	LATR	$P < 0.0015$ (Low = Med) > High
ERSL	$P < 0.0035$ (Low = Med) > High		

NS = Non-significant

RABR = Right rectus abdominus muscle

ERSR = Right erector spinae muscle

ERSL = Left erector spinae muscle

LATR = Right latissimus dorsi muscle

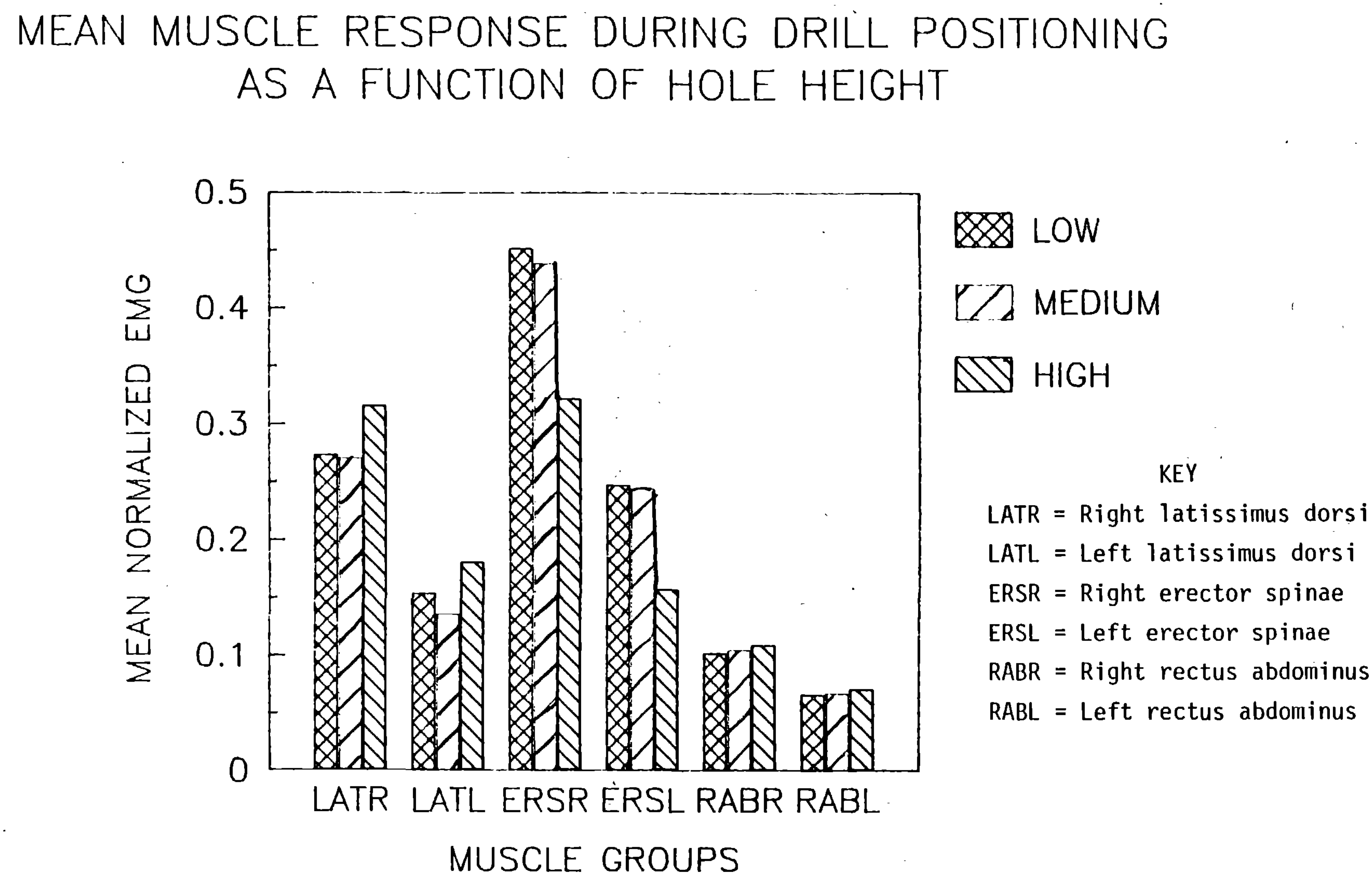


FIGURE 7–2: MEAN MUSCLE RESPONSE DURING POSITIONING AS A FUNCTION OF HOLE HEIGHT

PEAK MUSCLE FORCE WHILE POSITIONING THE JLD
AS A FUNCTION OF AN ADDITIONAL HANDLE

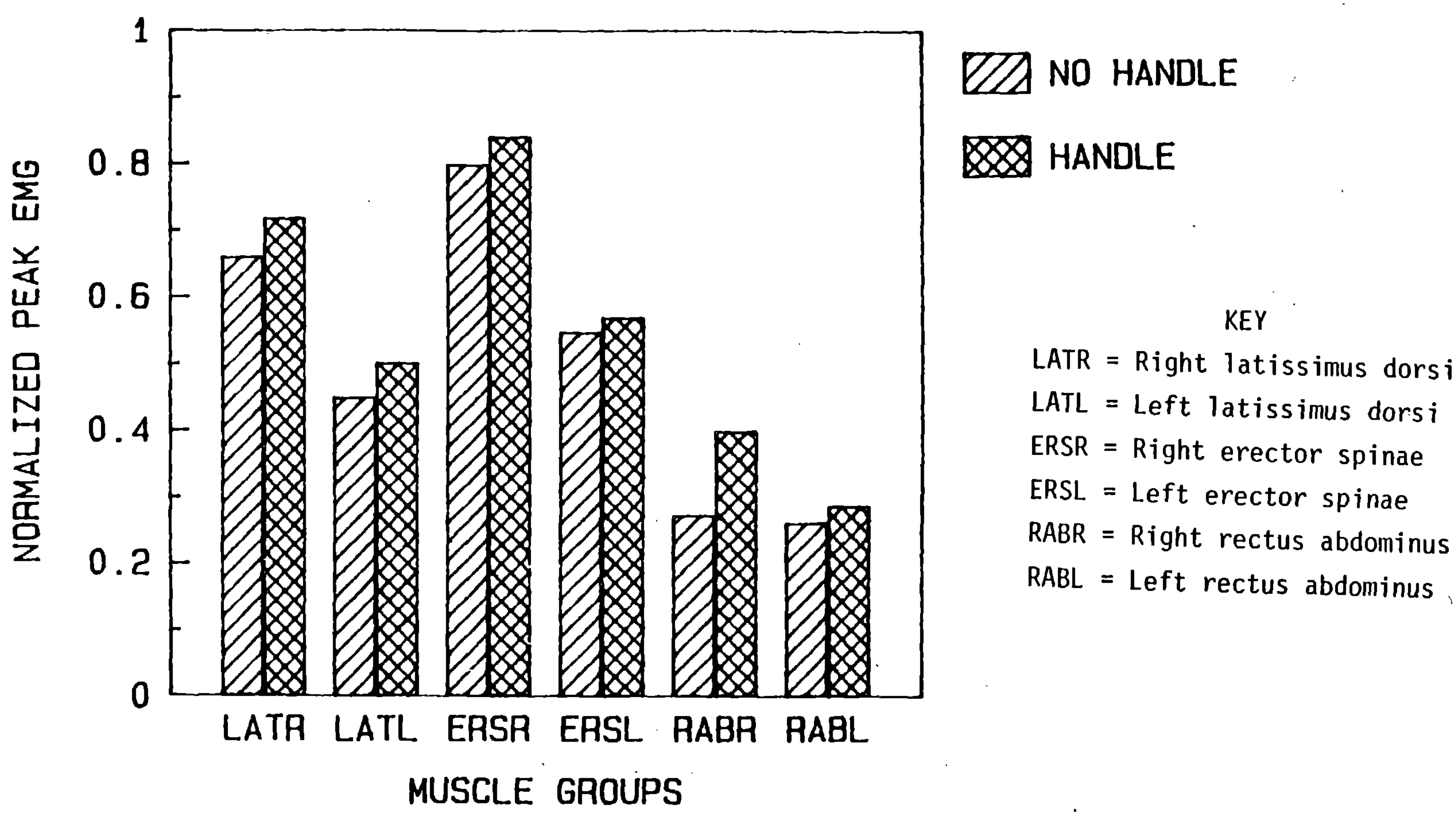


FIGURE: 7–3: PEAK MUSCLE RESPONSE DURING POSITIONING AS A FUNCTION OF HANDLE CONDITION

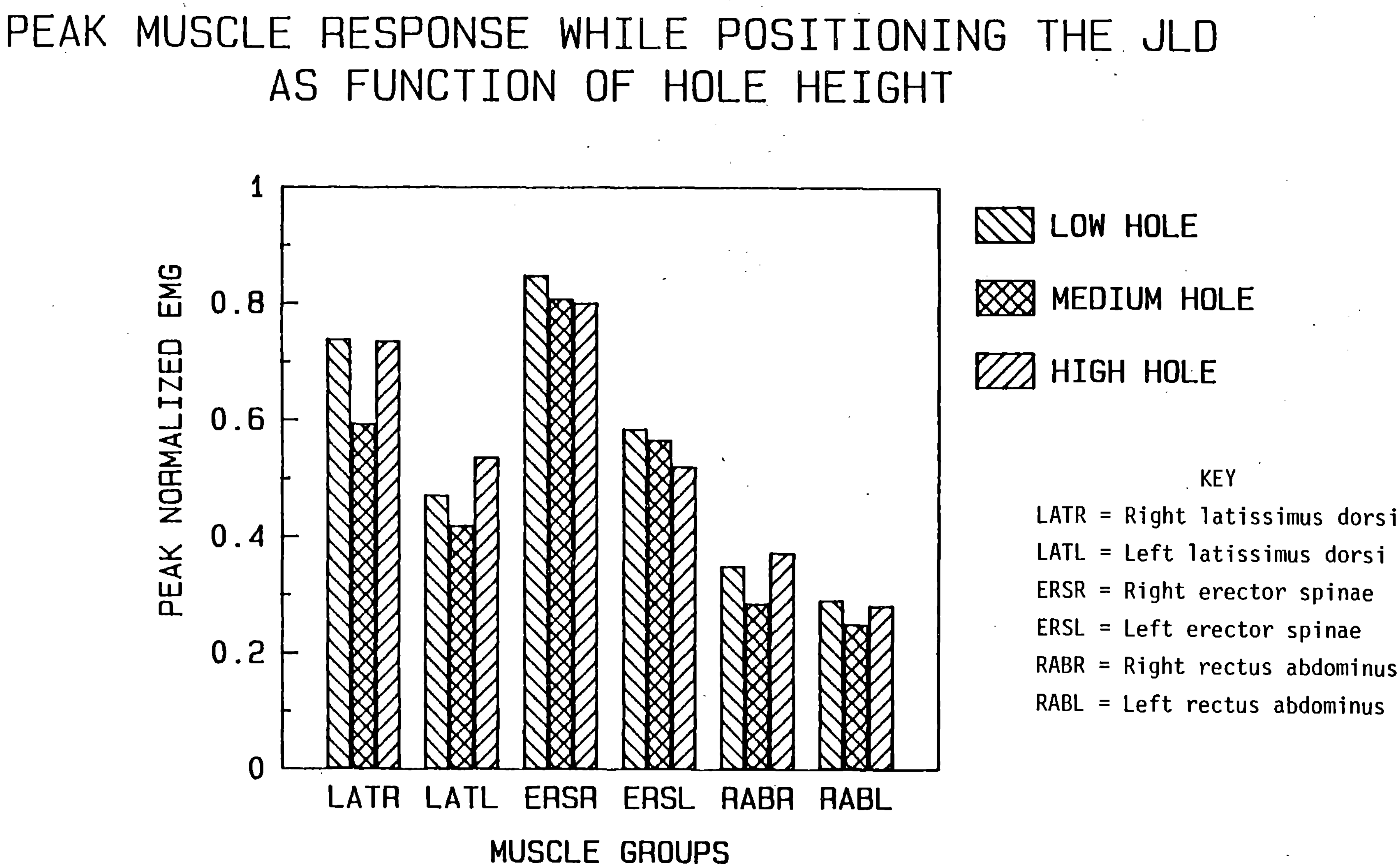


FIGURE 7–4: PEAK MUSCLE RESPONSE DURING POSITIONING AS A FUNCTION OF HOLE HEIGHT

TABLE 7–2

Task: Collaring

MEANS		PEAKS	
MANOVA EFFECTS:		**MANOVA EFFECTS:**	
SUBJECT	$P < 0.0001$	SUBJECT	$P < 0.0001$
HOLE HEIGHT	$P < 0.0001$	HOLE HEIGHT	$P < 0.0001$
FOLLOW UP ANOVAS:		**FOLLOW UP ANOVAS:**	
MUSCLES SHOWING SIGNIFICANT HOLE HEIGHT EFFECTS:		MUSCLES SHOWING SIGNIFICANT HOLE HEIGHT EFFECTS:	
LATR	$P < 0.0001$ HIGH > MED > LOW	LATR	$P < 0.0001$ HIGH > (MED = LOW)
LATL	$P < 0.0001$ HIGH > (MED = LOW)	LATL	$P < 0.01$ HIGH > (MED = LOW)
ERSR	$P < 0.0001$ LOW > (MED = HIGH)	ERSR	$P < 0.05$ N.S. Trend
RABR	$P < 0.0001$ (HIGH = MED) > LOW	RABR	$P < 0.0003$
RABL	$P < 0.004$ (HIGH = MED) > LOW		

LATR = Right latissimus dorsi
LATL = Left latissimus dorsi
ERSR = Right erector spinae
RABR = Right rectus abdominus
RABL = Left rectus abdominus

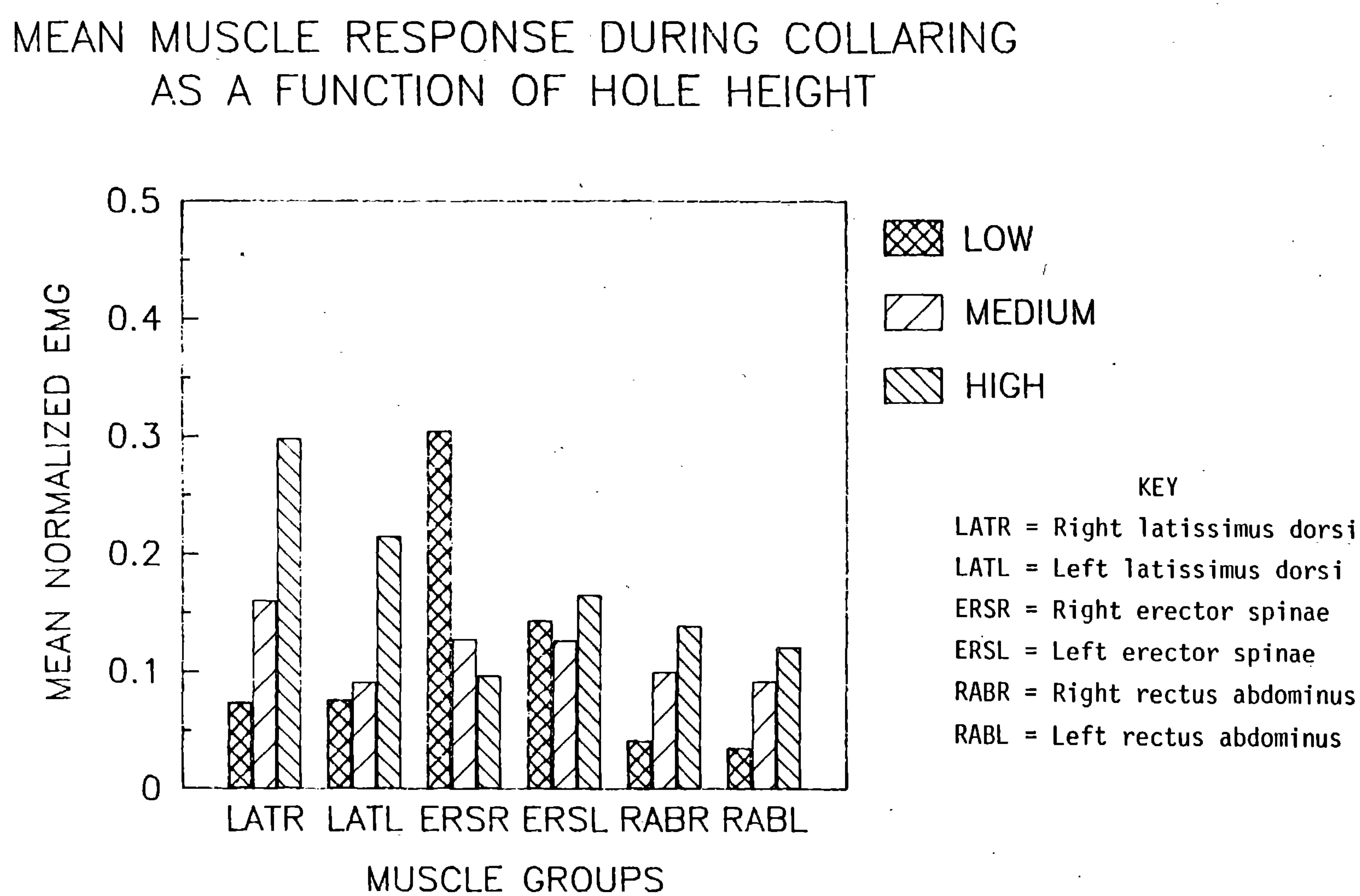


FIGURE 7—5: MEAN MUSCLE RESPONSE DURING COLLARING A FUNCTION OF HOLE HEIGHT

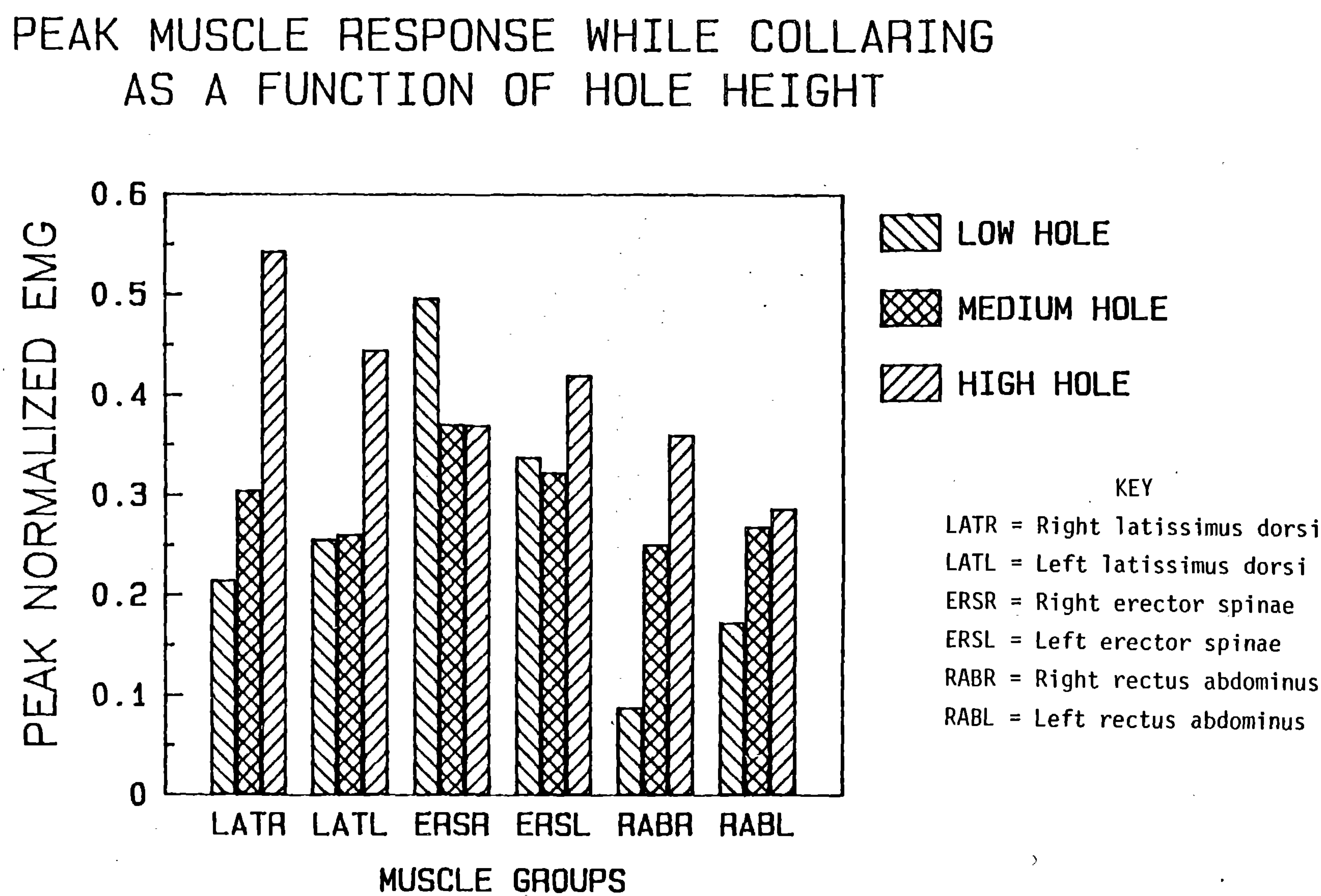


FIGURE 7–6: PEAK MUSCLE RESPONSE DURING COLLARING AS A FUNCTION OF HOLE HEIGHT

TABLE 7–3

TASK: REMOVAL

MEANS		PEAKS	
MANOVA EFFECTS:		MANOVA EFFECTS:	
SUBJECT	$P < 0.0001$	SUBJECT	$P < 0.0001$
HANDLE	$P < 0.03$	HANDLE	NS
HOLE HEIGHT	0.0006	HOLE HEIGHT	NS
HANDLE * HOLE HEIGHT	NS	HANDLE * HOLE HEIGHT	NS

FOLLOW UP ANOVAS:

MUSCLES SHOWING SIGNIFICANT HANDLE EFFECTS:	
NONE WITH	$P < 0.05$
MUSCLES SHOWING SIGNIFICANT HOLE HEIGHT EFFECTS:	
LATR	$P < 0.0005$ High > (Low = Med)
ERSL	$P < 0.0002$ (Low = Med) > High

LATR = Right latissimus dorsi muscle
ERSL = Left erêctor spinae muscle

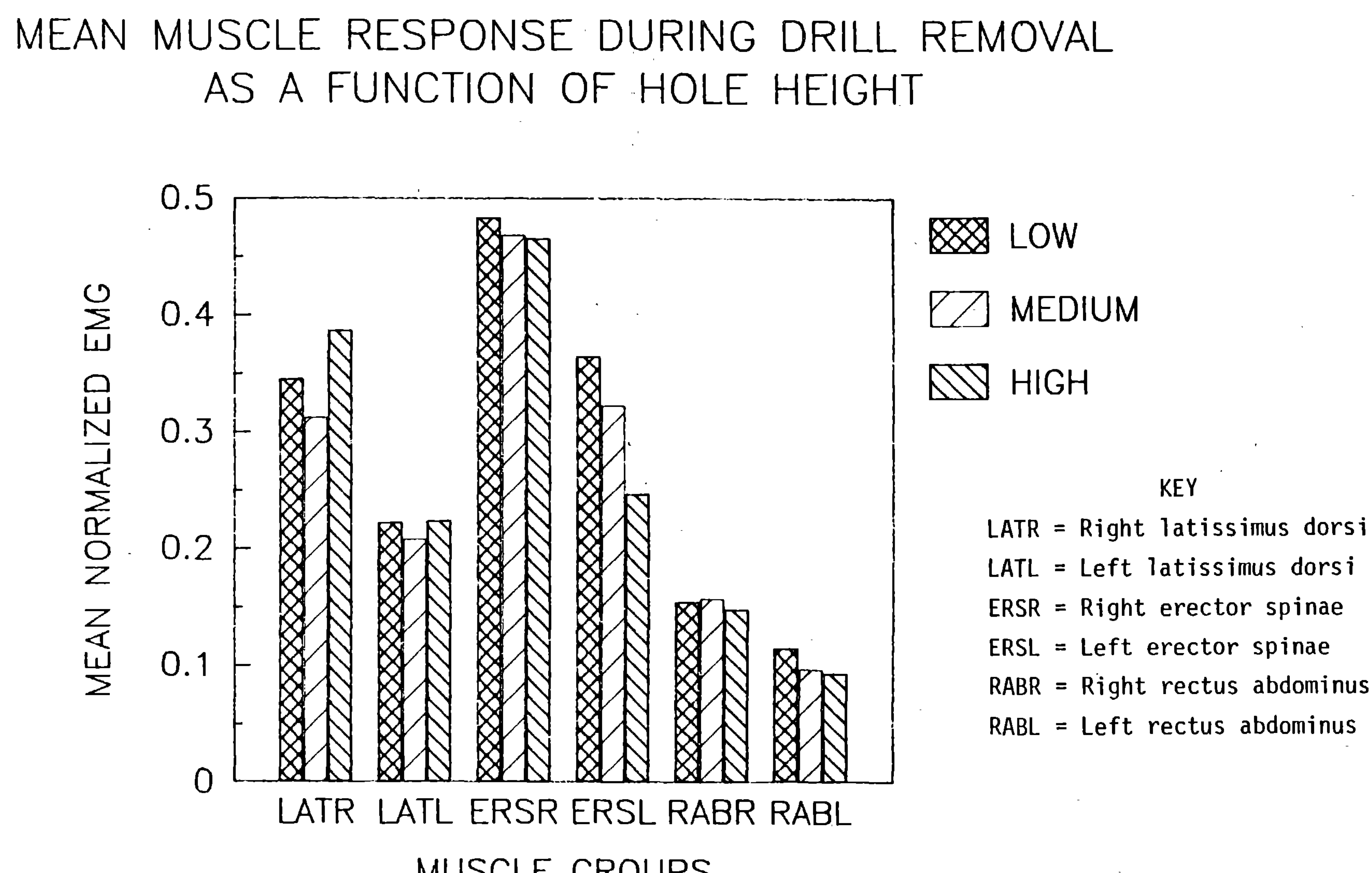


FIGURE 7—7: MEAN MUSCLE RESPONSE DURING REMOVAL AS A FUNCTION OF HOLE HEIGHT

DRILL POSITIONING: AVERAGE PEAK COMPRESSION

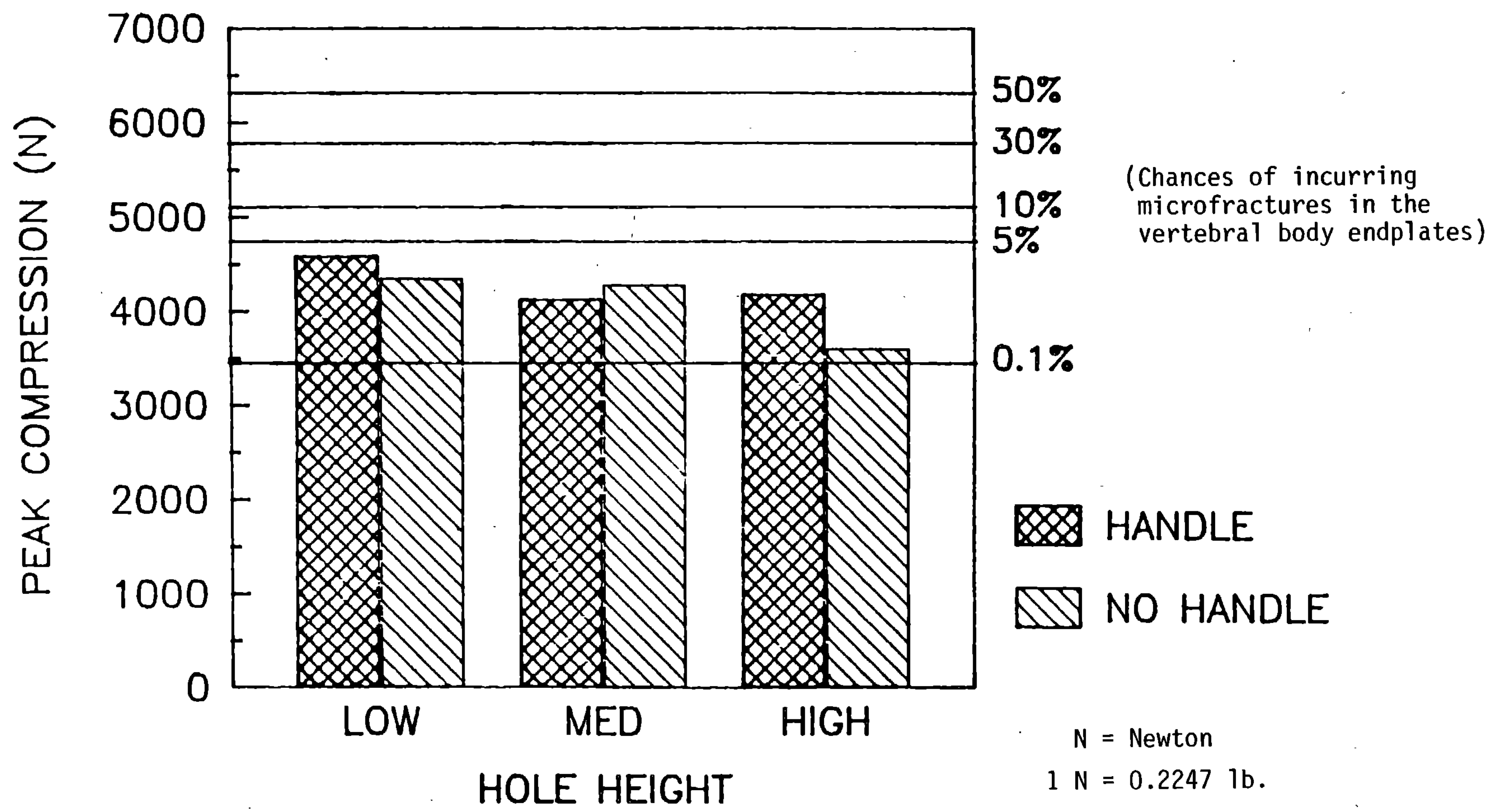


FIGURE 7–8: PEAK COMPRESSION WHILE POSITIONING JACKLEG DRILL

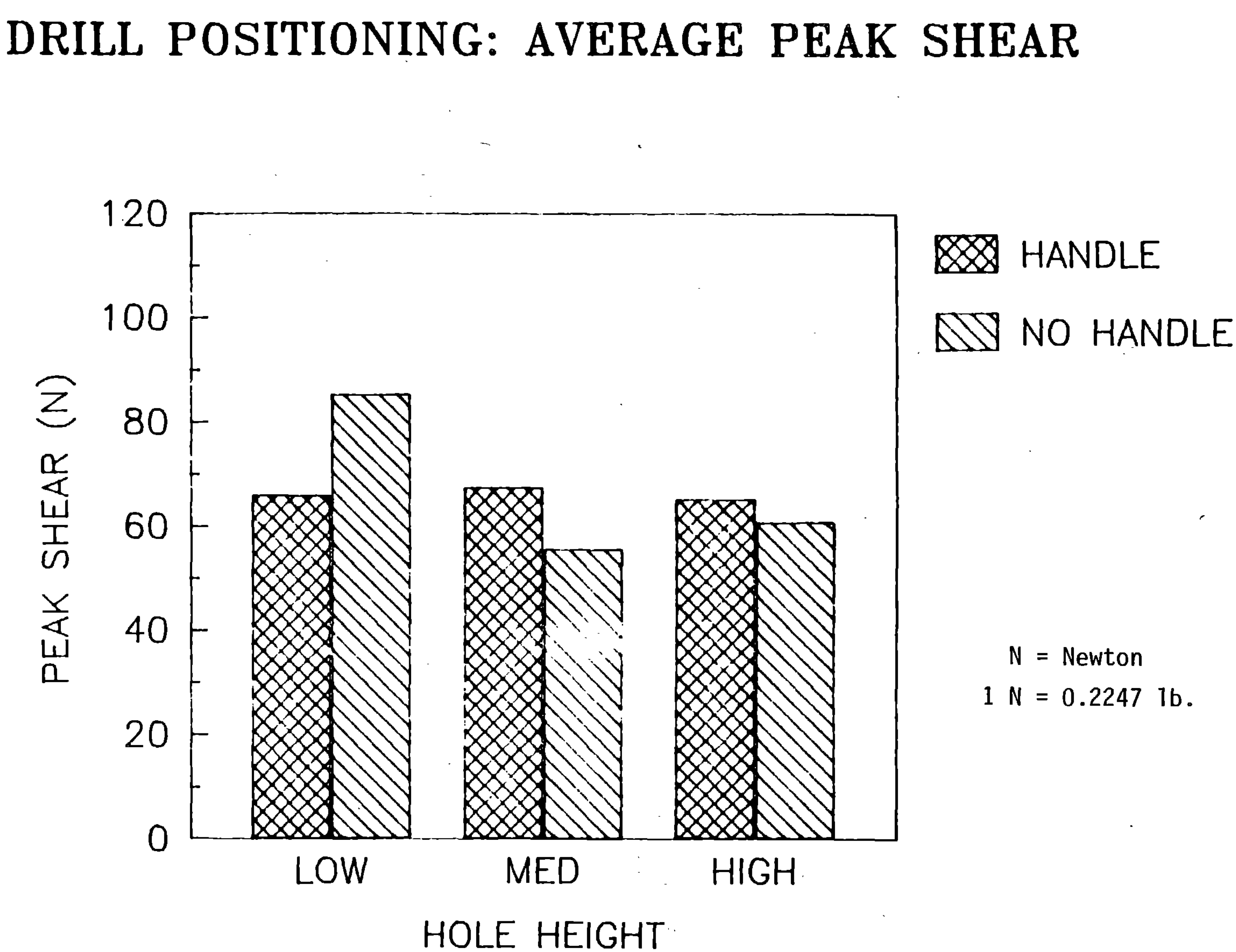


FIGURE 7–9: PEAK SHEAR WHILE POSITIONING JACKLEG DRILL

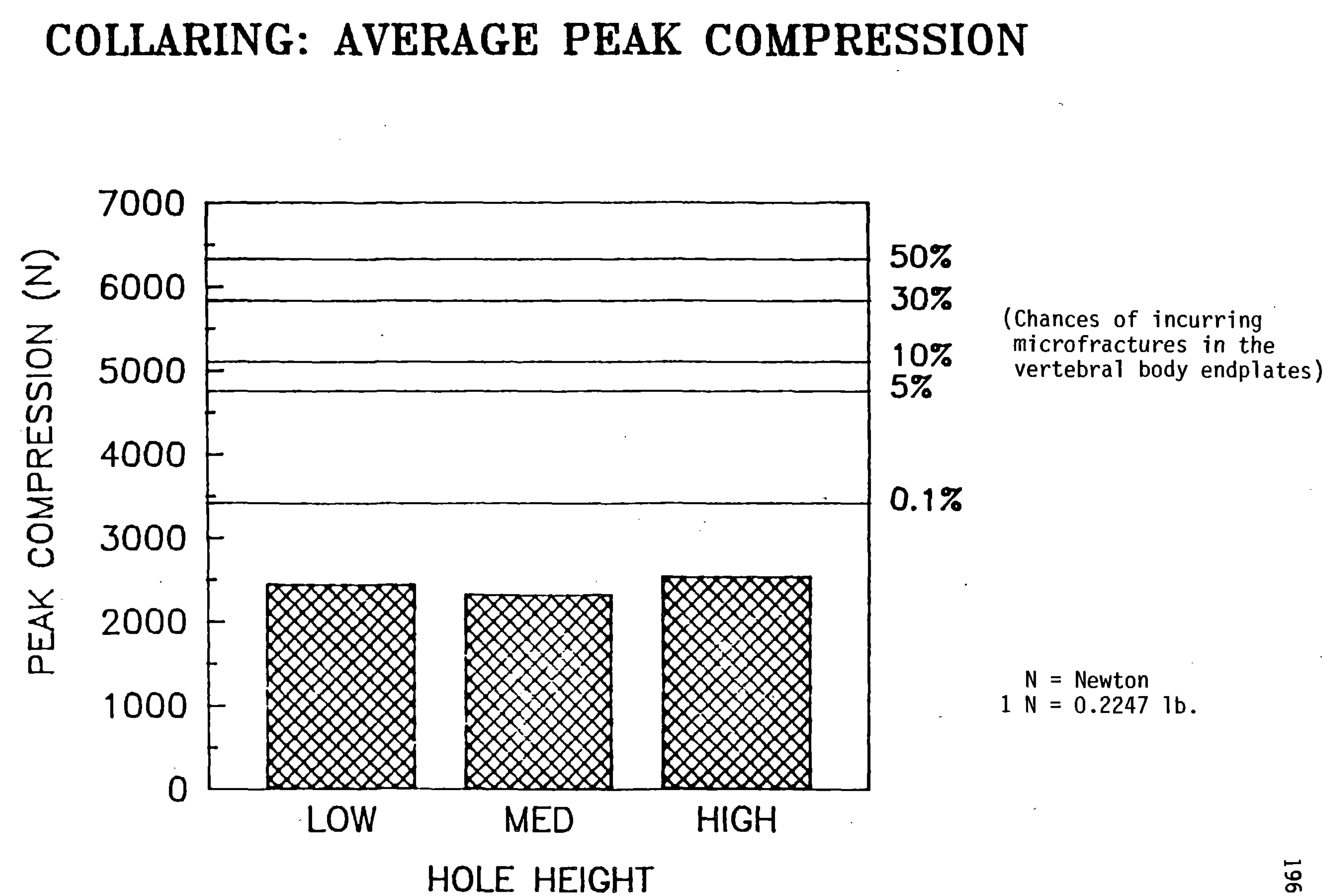


FIGURE 7—10: PEAK COMPRESSION WHILE COLLARING THE JACKLEG DRILL

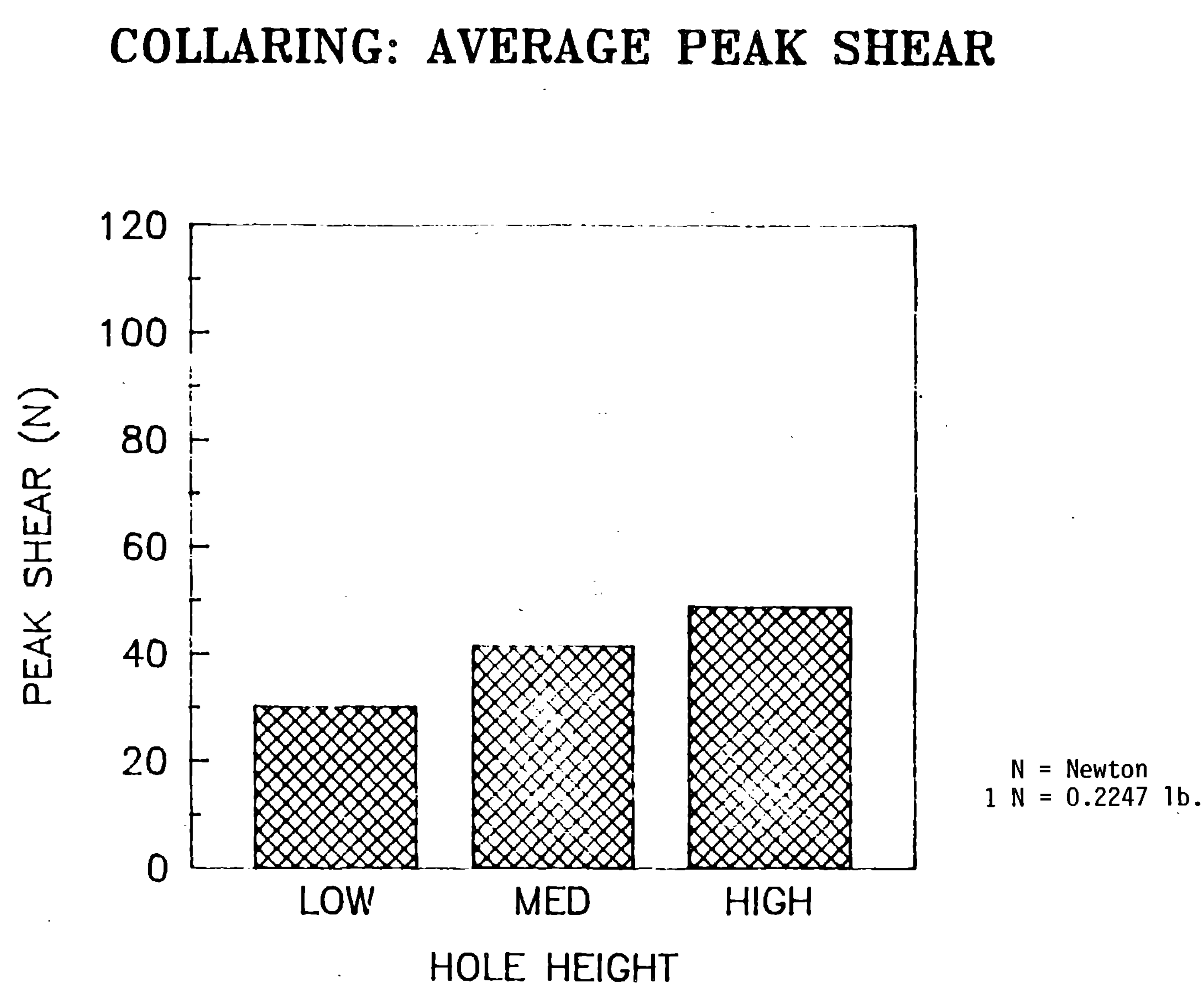


FIGURE 7—11: PEAK SHEAR WHILE COLLARING THE JACKLEG DRILL

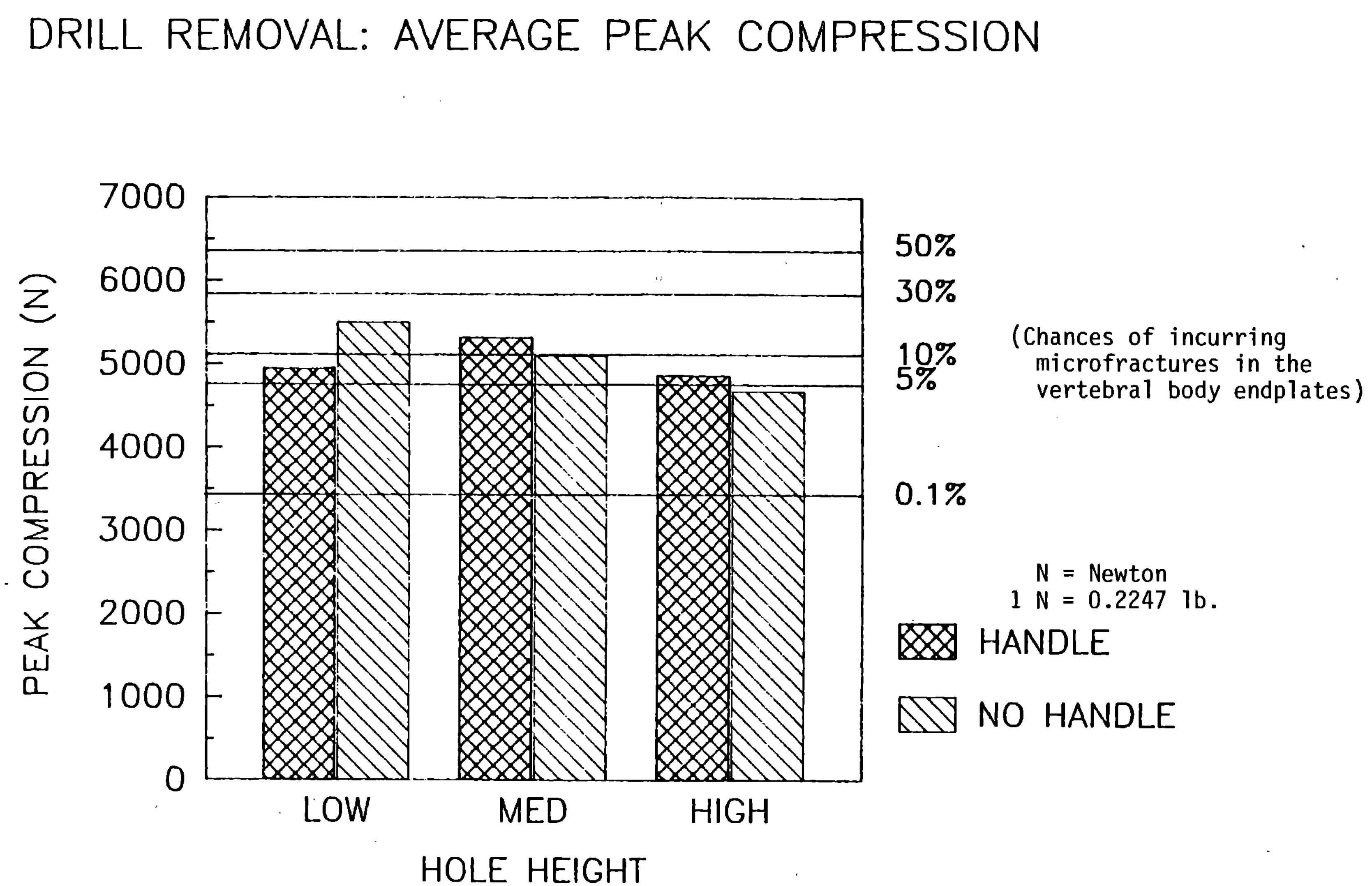


FIGURE 7—12: PEAK COMPRESSION WHILE REMOVING THE JACKLEG DRILL

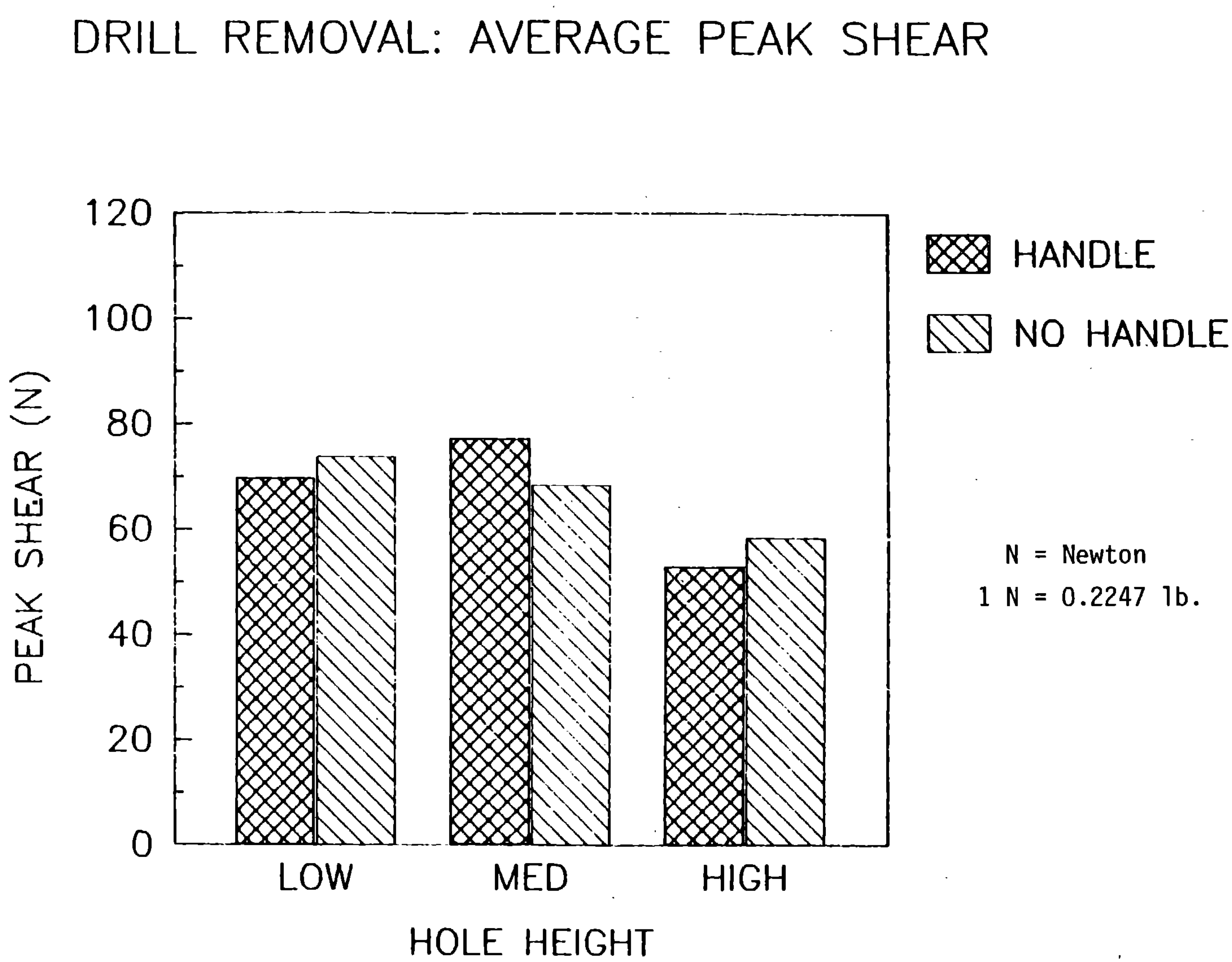


FIGURE 7–13: PEAK SHEAR WHILE REMOVING THE JACKLEG DRILL

TABLE 7-4
COMPRESSION AND SHEAR RESULTS

POSITIONING:		
COMPRESSION		PROBABILITY
	HOLE HEIGHT	P = 0.0582 Low > High
SHEAR		NON SIGNIFICANT
COLLARING		
COMPRESSION		NON SIGNIFICANT
SHEAR		NON SIGNIFICANT
REMOVAL:		
COMPRESSION		
	HOLE HEIGHT	P < 0.02 (Low = Med) > High
	HANDLE * HOLE HEIGHT	P < 0.05 (See Plot)
SHEAR		NON SIGNIFICANT

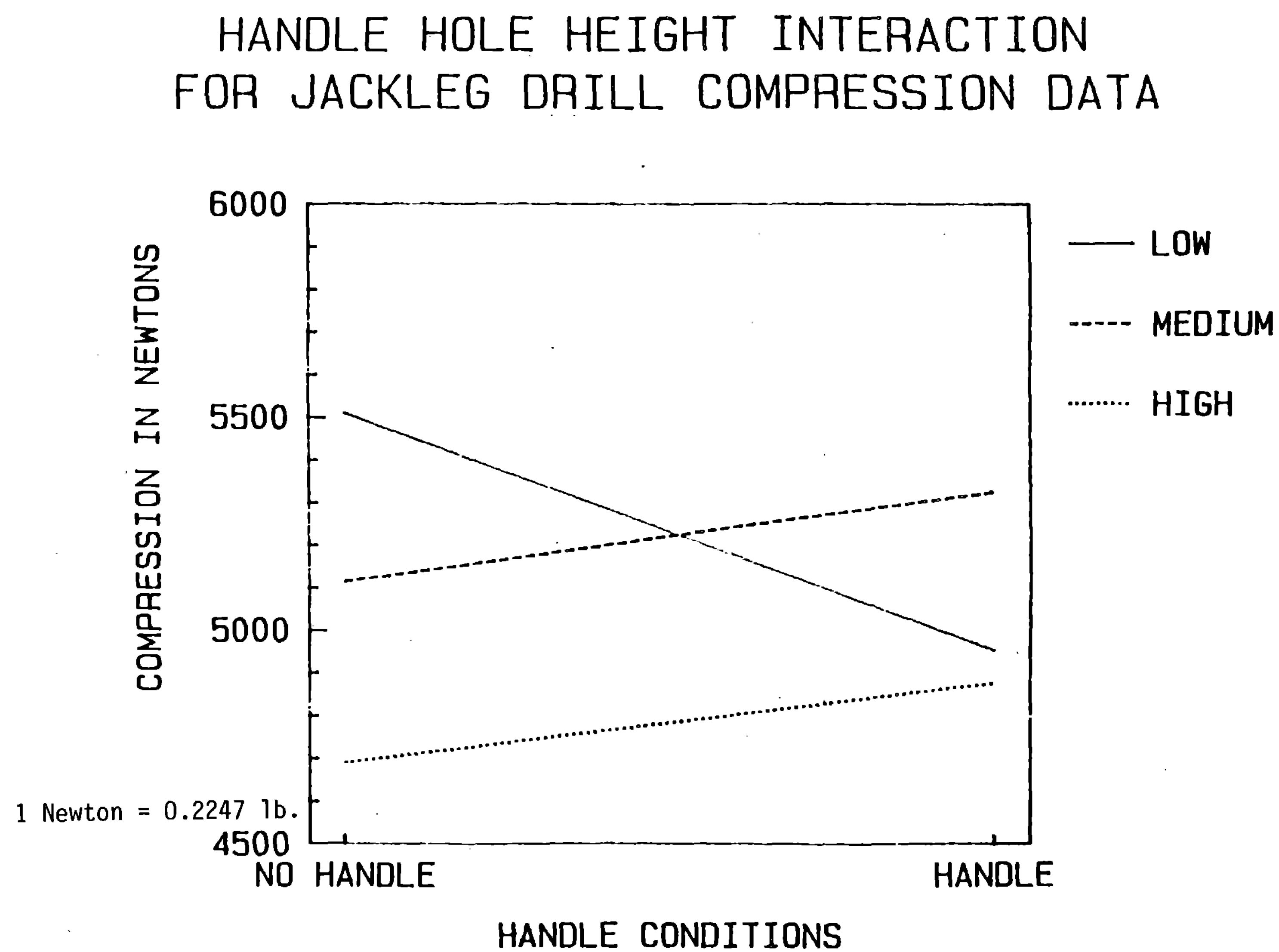


FIGURE 7-14: INTERACTION BETWEEN HOLE HEIGHT AND HANDLE CONDITIONS

Experiment 2

The reaction of the muscles to carrying the JLD was evaluated in this experiment. The task and handle effects were tested for statistical significance and these results are shown in Table 7-5. This table indicates a significant multivariate effect of subjects, handle, and task on the collective behavior of the mean muscle activity. The mean muscle reactions to the various tasks and handle conditions associated with JLD carrying are shown in Figures 7-15 and 7-16, respectively. The univariate ANOVAs indicate that there were significant differences in activities of the left latissimus dorsi, right and left erector spinae and left abdominal muscles as a function of the carrying tasks. These tests indicated significantly greater activity in the replacing task compared to the other tasks for the left latissimus dorsi muscle. The right erector spinae muscle exhibited increased activity for the transporting and turning tasks compared to the other tasks. The left erector spinae activity was least for the replacement task compared to the other tasks. Finally, the follow-up analyses show the left abdominal muscle to have greater activity during transporting compared with lifting the drill.

With respect to the handle conditions, only the activity of the right latissimus dorsi muscle was affected. The post-hoc tests indicated that the handle conditions required substantially more activity than the no-handle condition. This is clearly shown in Figure 7-16.

The peak muscle activities were also evaluated for significant differences. Table 7-5 indicates that significant multivariate handle, task, and subject effects are present, but their interactions are not significant. The peak reactions of the muscles to both task and handle conditions are shown in Figures 7-17 and 7-18, respectively. The univariate ANOVAs indicated that only the left latissimus dorsi muscle was responsible for the multivariate significance. This muscle displayed much greater activity for the replacing task compared to the other three tasks. Only the right latissimus dorsi muscle showed a significantly different response to the handle condition. As shown in Figure 7-18, this peak muscle activity was about 20 percent (of maximum capacity) greater during the handle-on condition. No other muscles displayed significant peak activity differences as a function of the experimental conditions.

The spine compression and shear forces were not computed for the JLD carrying experiment. The SIMULIFT model normally used to predict these forces is valid only for situations where trunk activity is static or the back is moving under constant velocity conditions. A review of the trunk activity in this experiment showed that these assumptions were not valid during the carrying tasks. Thus, neither spine compression nor shear forces could be analyzed.

TABLE 7–5

Jack Leg Drill Carrying Experiment

Means		Peaks	
Manova Effects:		**Manova Effects:**	
Subject	P < 0.0001	Subject	P < 0.0001
Handle	P < 0.0002	Handle	P < 0.0001
Task	P < 0.0001	Task	P < 0.0001
Handle • Task	NS	Handle • Task	NS
Follow Up Anovas:		**Follow Up Anovas:**	
Muscles Showing Significant Handle Effects:		**Muscles Showing Significant Handle Effects:**	
LATR	P < 0.0001 (Handle > No Handle)	LATR	P < 0.0001 (Handle > No Handle)
Muscles Showing Significant Task Effects:		**Muscles Showing Significant Task Effects:**	
LATL	P < 0.0001 Rep*> (Lift = Walk = Turn)	LATL	P < 0.0001 Rep*> (Lift = Walk = Turn)
ERSR	P < 0.0001 (Turn = Walk) > (Lift = Rep)		
ERSL	P < 0.008 (Turn = Walk = Lift) > Rep		
RABL	P < 0.02 Walk > Lift		*Rep = Replace Drill

LATL = Left latissimus dorsi muscle.

LATR = Right latissimus dorsi muscle

ERSR = Right erector spinae muscle

ERSL = Left erector spinae muscle

RABL = Left rectus abdominus muscle

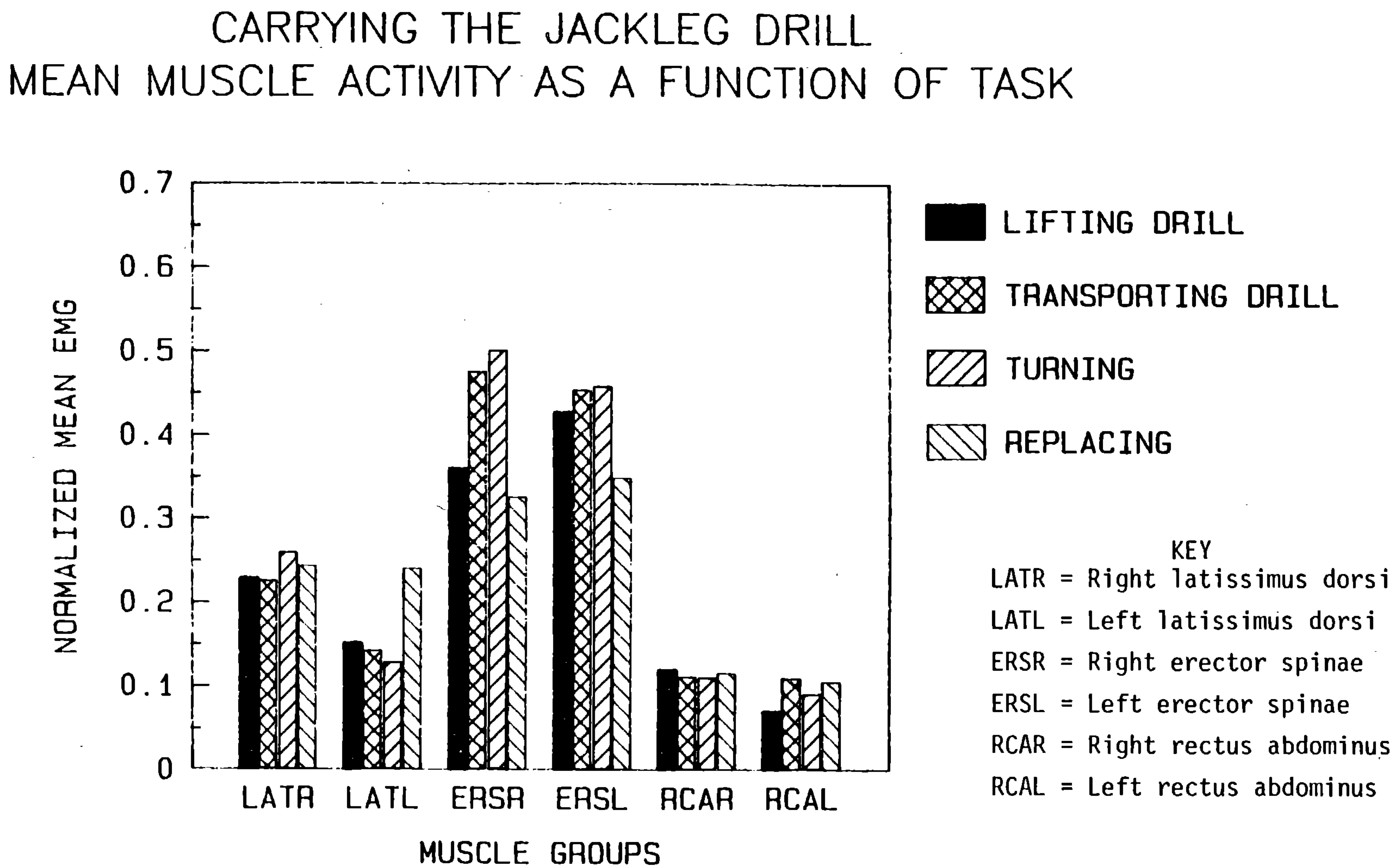


FIGURE 7–15: MEAN MUSCLE RESPONSE AS A FUNCTION OF CARRYING TASK ELEMENT

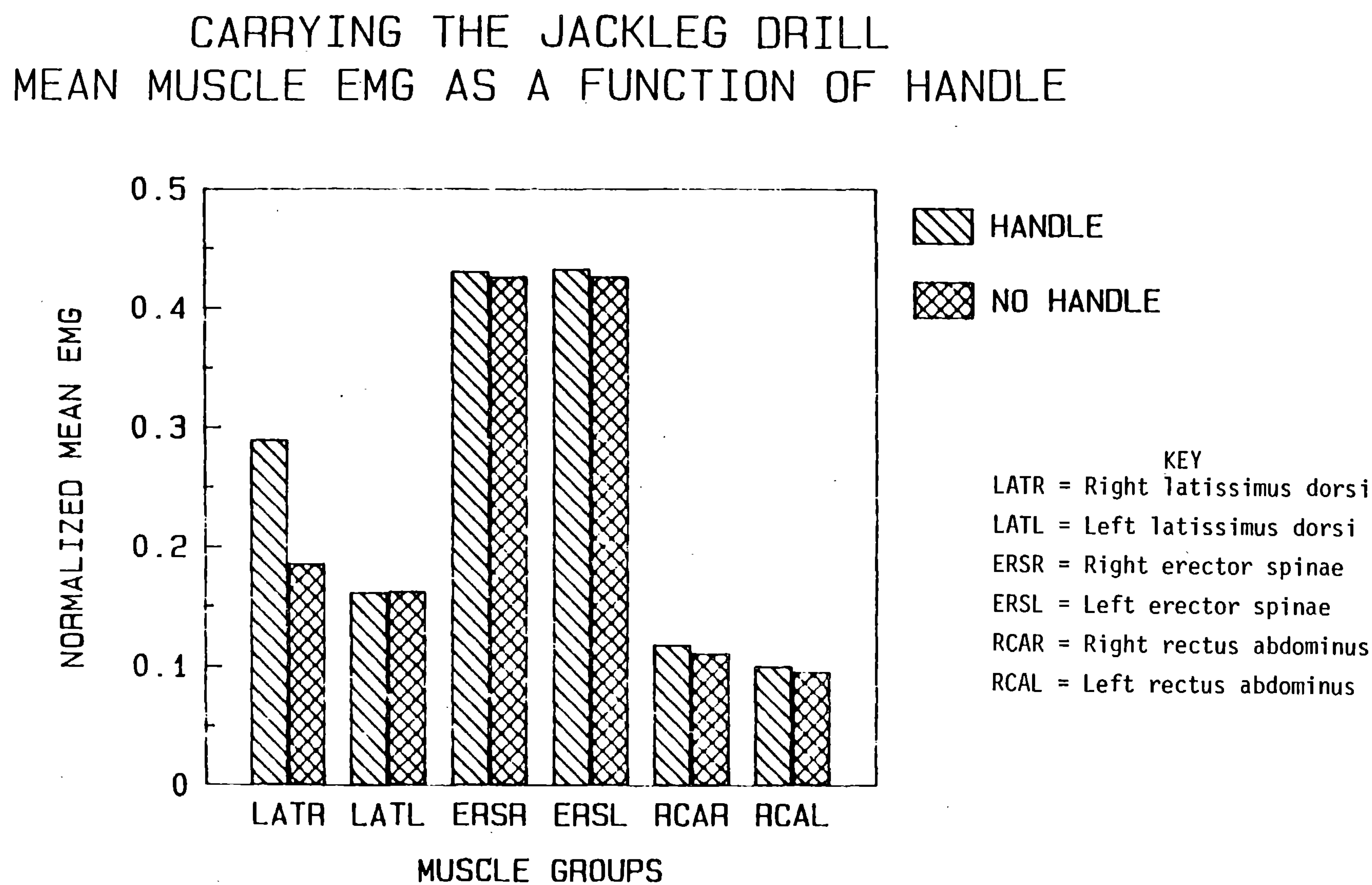


FIGURE 7—16: MEAN MUSCLE RESPONSE AS A FUNCTION OF HANDLE CONDITION

CARRYING THE JACKLEG DRILL
PEAK MUSCLE ACTIVITY AS A FUNCTION OF TASK

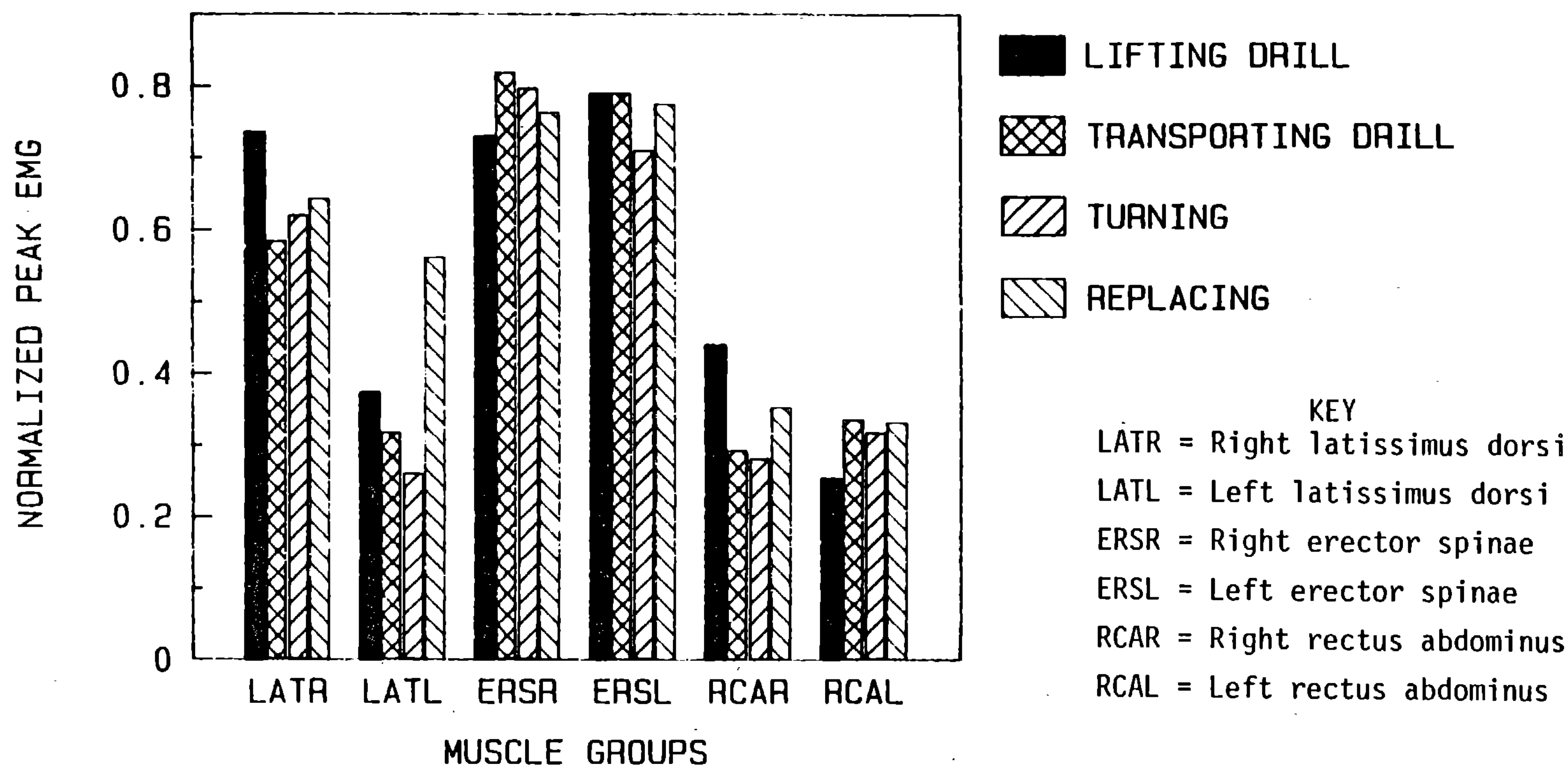


FIGURE 7—17: PEAK MUSCLE RESPONSE AS A FUNCTION OF CARRYING TASK ELEMENT

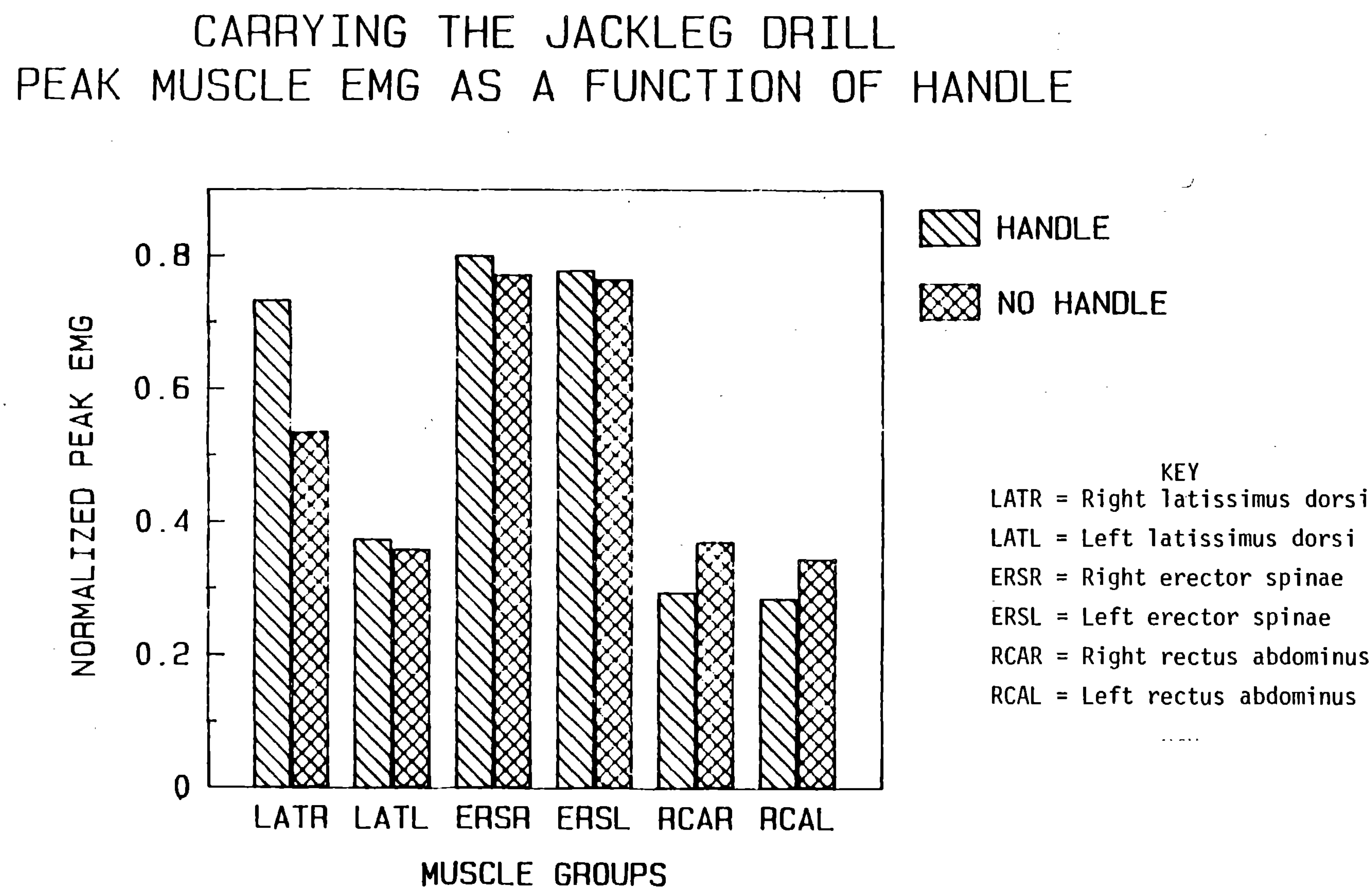


FIGURE 7–18: PEAK MUSCLE RESPONSE AS A FUNCTION OF HANDLE CONDITION

DISCUSSION

These results have evaluated the risk of back loading due to the performance of the JLD tasks that were identified as potential problem activities via the task analysis and ergonomic assessment. This experiment evaluated the positioning, collaring, and removal tasks associated with JLD use and the lifting, transporting, turning, and replacement tasks associated with JLD transport.

The JLD use will be discussed first. This evaluation has shown that the strain experienced by the trunk muscles during drill positioning is a function of both the handle and the height of the hole being drilled. The average and peak load on the right abdominal muscle increased by about 10 percent of maximum when the handle was used to position the drill. The other muscles did not display any significant change in activity. Hole height appeared to have a much greater influence on the activity level of the muscles. The mean activity of both erector spinae muscles significantly increased (about 20% of maximum) when subjects positioned the drill at the low and medium height holes compared to the high holes. This is particularly important since the erector spinae muscles are very large in their cross-sectional area which means that a small increase in muscle activity results in a large increase in muscle load. The spine compression assessment evaluation confirmed these findings. This assessment indicated that the low hole condition produced significantly greater compression on the spine compared to the high hole condition. When the compression values were compared with the risk of vertebral end plate fracture, it was found that there is between a one and four percent risk of fracture. Even though these values are low, the cumulative effect of positioning the drill should be kept in mind. This task should be considered potentially hazardous.

This analysis has also found that the addition of a handle does not offer any biomechanical advantage during positioning, but actually increases the loading on the trunk. The assessment of the collaring task showed that the load on the muscles was not affected by the presence of a handle, but was affected by the height of the hole. A trade-off in muscle loading was observed in this case with increased activity occurring in the latissimus dorsi muscles and abdominal muscles while collaring the high hole, and increased activity occurring in the erector spinae muscles while collaring the low hole. The spine-force analysis showed that this may truly be a tradeoff in that there is no statistically significant difference in the compression or shear spine forces as a function of the various experimental conditions. The task of collaring would not be considered risky in terms of spine loading. The levels of compression imposed upon the spine during the performance of this task are well within acceptable limits.

The drill removal task indicates that both the handle and hole-height factors have an effect on trunk muscle activities. In this case, we again see a trade-off in muscle load between muscle groups. The latissimus dorsi muscles exhibit greater activity at the high holes, whereas the erector spinae muscles follow the opposite trend. The true risk of this task can be appreciated by observing the spine compression predictions. This analysis shows both a hole-height effect, as well as an interaction effect on spine compression. The low and medium height holes significantly increase spine compression. However, this increase can be mediated at the low hole by including a handle on the drill. The spine-compression analysis indicated that the risk associated with this task was between 4% and 20%, which is much greater than the risk associated with any other task. This risk can be reduced by an average of 12% at the low hole through the use of a handle. However, that is only true for the low hole. The risk associated with this task may be even greater considering that the task analyses revealed a tendency for the the drill steel to stick in the hole. This event would create even greater forces on the back, particularly if a sudden unexpected jolt is imposed on the spine.

This analysis has indicated that there are components of the JLD-use tasks that are hazardous. Particularly, removal and to a lesser extent the positioning tasks have been identified as risky. Based upon the findings of this study, several solutions are indicated that may improve this situation.

First, reducing the weight of the tool may reduce the loading upon the spine. However, significant weight is needed to stabilize the leg of the tool so it grips the floor of the mine. Also, this would not affect the loading to the back due to a stuck drill steel during JLD removal. That task has been identified as one of the most hazardous.

Second, this study has shown that the risk of injury can be reduced by providing a handle for low-hole drill removal. However, under other circumstances, the spine loading actually increases when the handle is used. Thus, one possible solution is to provide a handle and training for the operator of this tool. Specifically, training should be provided as to when to use or not use the handle. The problem with this solution is that training effects generally do not last very long and the worker may actually be worse off with this tool redesign. Also, as seen in the analysis, even using the handle at the low hole, the spine compression values are unacceptable.

Finally, the recommended solution would be to mount the JLD on an articulated arm that can be connected to a mining vehicle. As an alternative, for mines where drillers commonly work from the top of muck piles, an articulated arm could be mounted to a substantial support post that would be wedged between the roof and the floor. This would eliminate the need to physically manipulate the tool by using exertions that may overstress the trunk system.

The carrying task components were also evaluated in this study. This evaluation indicated that both handle and hole height conditions affected the load on the trunk muscles. Inclusion of a handle for use during the transporting task had the effect of increasing the activity of the right latissimus muscle by about 10%. All other other muscles were unaffected by handle use. When the tasks associated with carrying were considered, it was apparent that the erector spinae muscles were the most active muscle group in the trunk. The average muscle activity approached 50% of maximum for most tasks, and peak activities as high as 80% of maximum were observed for certain task components. This muscle group was significantly more active during the transporting of the drill and during the turning motion as compared to the lifting or replacing activities. The left latissimus dorsi muscle also showed an increase of about 10% during the replacement task. These patterns appear typical of a manual materials handling task. The erector spinae muscles appear to bear most of the load during the drill replacement and the muscle activity increases during the transporting and turning tasks. This is probably due to a static overload condition occurring in the back muscles. Since the muscles are fatiguing during this time, more muscle fibers must be recruited to maintain the desired force and posture. The latissimus dorsi muscles, on the other hand, respond to changes in activity such as lifting or lowering the drill. The fact that only one of these muscles changes its activity indicates that the tasks impose asymmetric forces on the trunk.

Even though spine-force predictions were not generated for the transporting activities task, the magnitude of the muscular activity of the spine-supporting structures can be used as a basis of comparison for spine compression. The spine compression would be expected to be quite high during the lifting and lowering tasks since the erector spinae peak activities are as high as 80% of maximum. Similar muscular activity of the erector spinae was observed during the stressful removal task. Thus, since this muscle group is one of the main loading muscles of the spine, the total compression during the carrying tasks is expected to be unacceptable.

The same recommendations that hold for the drilling operation would apply in the carrying task. The preferred recommendation is to mount the drill on an articulated arm that would be attached to mining vehicles. This modification is reasonable for transporting the drill. However, there would still be instances where the drill would have to be lifted and manipulated by hand, for example during repair or maintenance tasks. Under these circumstances, another mechanical-assist device should be used or the task should be performed by two workers simultaneously. It should also be pointed out that the handle tested in this experiment is not recommended for use in carrying the drill. It is obvious from this study and the epidemiological data that this is a tool that should not be handled by a worker if the intent is to control the low-back disorder incidence rate.

CHAPTER 8: JACK EXPERIMENT

INTRODUCTION

Jack use was responsible for the second greatest number of lost days in underground coal mining during the 6-year period of interest. The epidemiological study indicated that exertion injuries were particularly common. In fact, exertion-type of jack injuries account for the second greatest number of lost days. The sequence analysis indicated that these injuries occurred predominantly to the trunk of the worker.

The task analysis indicated that there were essentially four components of the jack use task. This analysis also indicated that the tool is often operated while in a kneeling, as well as standing posture. The ergonomic analysis identified the posture while using the tool, the position of the tool handle (with respect to vertical), and the speed of movement of the handle as variables that may affect the risk of trunk injury during the use of the jack.

As with the previous experiments, this effort focused upon EMG activity of the internal trunk structures during work. However, in this study the effect of working in a kneeling posture was expected to significantly increase the loading of the trunk since fine exertion adjustments could not be performed with the legs. Therefore, the external obliques were also investigated to get a more accurate picture of trunk loading during jack use.

METHODS

Subject

One subject was used in this pilot study of trunk muscle control while using a jack. The subject weighed 70 kg and was 185 cm in height. Other anthropometric measures included trunk width and trunk depth which were 28.3 and 18.7 cm, respectively.

Experimental Design

The experiment sampled muscle force in 2 postures (kneeling and stooped postures), 3 static conditions (0°,30° and 60° from vertical), and 3 dynamic conditions (12, 36, and 60 deg/seec). The experiment was blocked on levels of posture. Conditions within each block were randomized. The subject participated in all cells of the experiment.

The dependent measures included muscle forces from 8 trunk muscles, the torque generated on the Cybex dynamometer, and the position of the lever arm in space.

Apparatus

The subject was tested using a Cybex isokinetic dynamometer. The dynamometer was positioned near the edge of the platform where the subject stood (or kneeled). A 102-cm bar was attached to the dynamometer to simulate the lever observed when using jacks underground. The axis of rotation was set

20 cm above the platform. This allowed a range of motion similar to that found when using track jacks. Both torque and position data were collected from the Cybex and stored with the EMG data in the computer for later analysis. The subject's EMG was collected via the same system of electrodes, preamplifiers, amplifiers, and integrators described in the previous two experiments.

Procedure

The subject's skin was prepared for electromyography as described in the scaling bar and jackleg drill experiments. The only exception was that two additional muscles, the left and right external obliques, were sampled in this study. The jacking task was thought to contain considerable asymmetric loading to which the external oblique muscles would be sensitive.

Two postures were used in the testing: a kneeling and a stooped posture. The initial testing posture was determined randomly, as were the order of the subsequent conditions. With each posture, 6 conditions were tested. The three static conditions differed with respect to the position of the bar coming from the Cybex. These positions were 0°, 30°, and 60° from the vertical. Likewise, the three dynamic conditions differed with respect to the velocity of the bar during the test. Based on pilot work with a real track jack and our underground observations, the three velocities selected for testing were 12, 36, and 60 degrees per second (deg/s). The subject was instructed to give a maximal exertion during each condition. Each exertion was performed once with a 1-minute rest period between them.

RESULTS

The results of this study indicate that torque production increased as the jack handle angle increased from vertical. This trend held for both the kneeling and stooped positions. When velocity was considered, torque production decreased as a function of increasing velocity. This trend also held true for both the kneeling and stooped postures.

When torque production was considered as a function of posture, several differences were noted. First, when static exertions were considered, the kneeling posture resulted in an average loss of 29% in the stooped torque when considered over all angles. Second, when velocity conditions were considered, the slow velocity conditions (12 and 36 deg/s) resulted in slight gains (4% to 8%) in torque production while in the kneeling posture. A significant loss in torque production (21%) in the kneeling posture was observed when the wrench angular velocity was set at 60 deg/s.

Trunk muscle activity during the performance of the experimental tasks is shown in Figures 8-1 and 8-2 for the static and dynamic exertions, respectively. Of particular interest is the observation that the activities of the right and left latissimus dorsi and the right erector spinae muscle increased significantly in the kneeling postures during the production of static force. In fact, the activity of the right erector spinae (ERSR) increased by over 467% in the kneeling posture when compared to the stooped posture, with the bar at 60° from the vertical. Less prominent but substantial decreases in activity of the remaining trunk muscles were noted for the static 0° and static 30° exertions when the kneeling postures were compared with the stooped postures. This trend indicates that substantial asymmetric loadings occur in the trunk when kneeling as compared to stooped. These, as well as other trends, are evident from Figure 8-1.

Differences in activities of the trunk muscles during dynamic activity while in kneeling and stooped-postures are shown in Figure 8-2. This figure indicates that the left latissimus dorsi (LATL), ERSR, and left erector spinae (ERSL) muscles are generally more active in the kneeling posture if dynamic force is exerted upon the jack. The remaining trunk muscles (the abdominals and the obliques) are generally more active in the stooped posture, but not to the same degree as the back muscles. This trend also indicates that significant asymmetric loading of the trunk occurred when dynamic force was exerted on the jack. However, no clear relation between the velocity level and degree of muscle activation or asymmetric loading emerged.

Spine compression and shear forces were also computed as the subject used a mining jack to lift an object. This task represented a situation that was more realistic than attempting to exert force against a dynamometer. Spine forces were computed using the SIMULIFT model developed by Reilly and Marras (1987). The results of this evaluation are summarized in Figure 8-3. This figure indicates that peak spine compression was significantly larger when the subject worked while kneeling as compared to stooped. Substantially more shear forces were predicted to occur on the spine in the kneeling posture compared with the stooped posture. Both of these factors have been associated with an increased risk of a back injury. Hence, using the jack while in the kneeling posture appears to put the worker at a greater risk of injury.

DISCUSSION

The epidemiology study and the task analyses have identified low-back problems as the main risk associated with the jack in underground mining. The results of this experimental investigation suggest that back injury risks are related to worker posture when using the jack. It should be kept in mind that this study represents a cursory investigation and this discussion is based on a single subject population. However, these results can still provide some insight into the low-back disorder risks associated with the use of this tool.

Collectively, these results indicate that the stooped posture would be preferred to the kneeling posture during the use of this tool. This is true for several reasons. Under most conditions more force can be exerted on the jack handle when in the stooped posture than when kneeling. This is true for all static exertion conditions and the 60 deg/s dynamic condition. The two slower dynamic conditions show a slight increase in strength in the kneeling posture. However, with a larger subject population, it is expected that these differences would not be significant. Thus, generally people are stronger in the non-kneeling positions. It is believed that this is due to the ability of the worker to adjust the lower extremities during the performance of the task

PERCENT CHANGE IN PEAK EMG IN KNEELING POSTURE RELATIVE TO STOOPED POSTURE (STATIC)

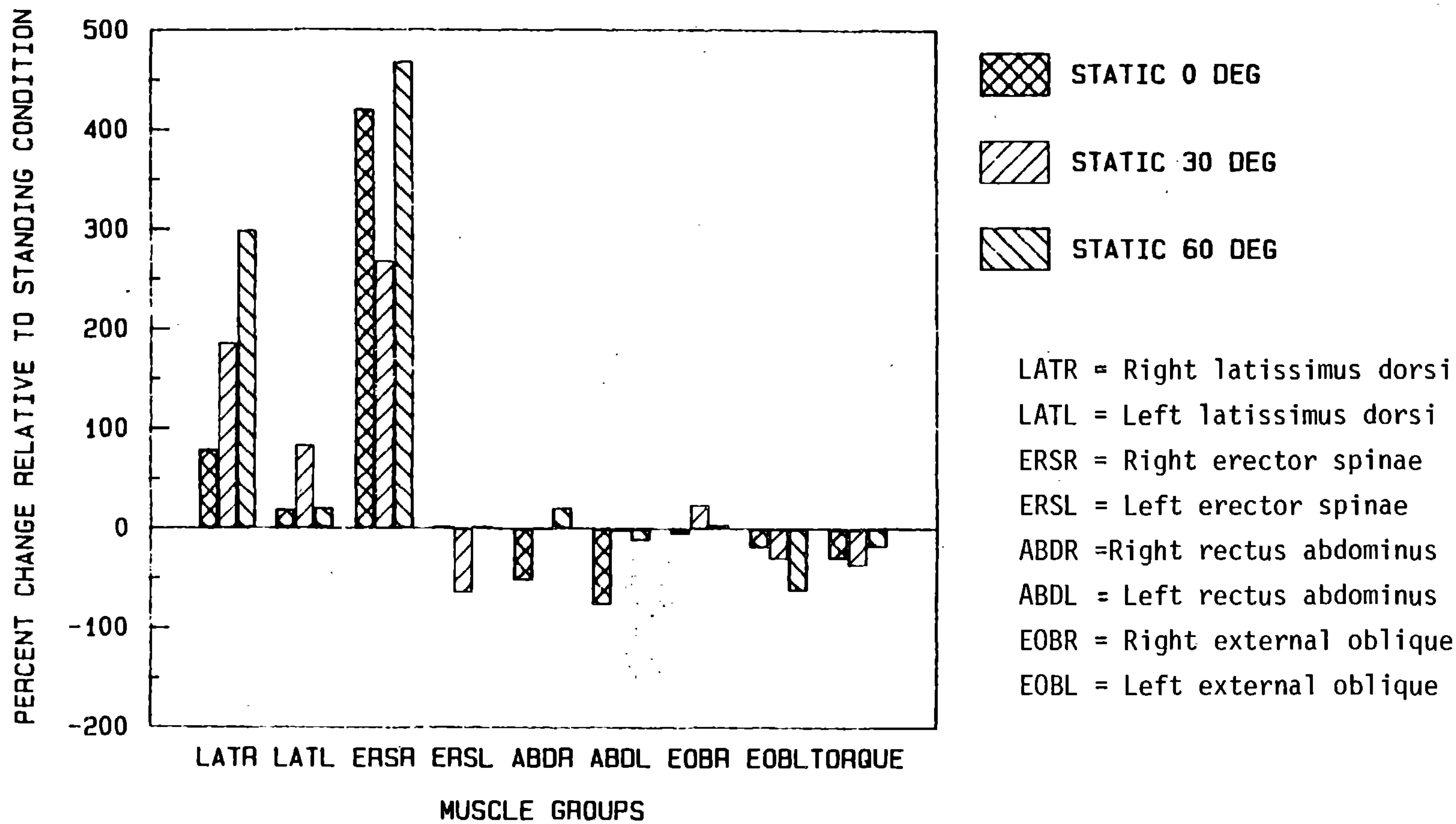
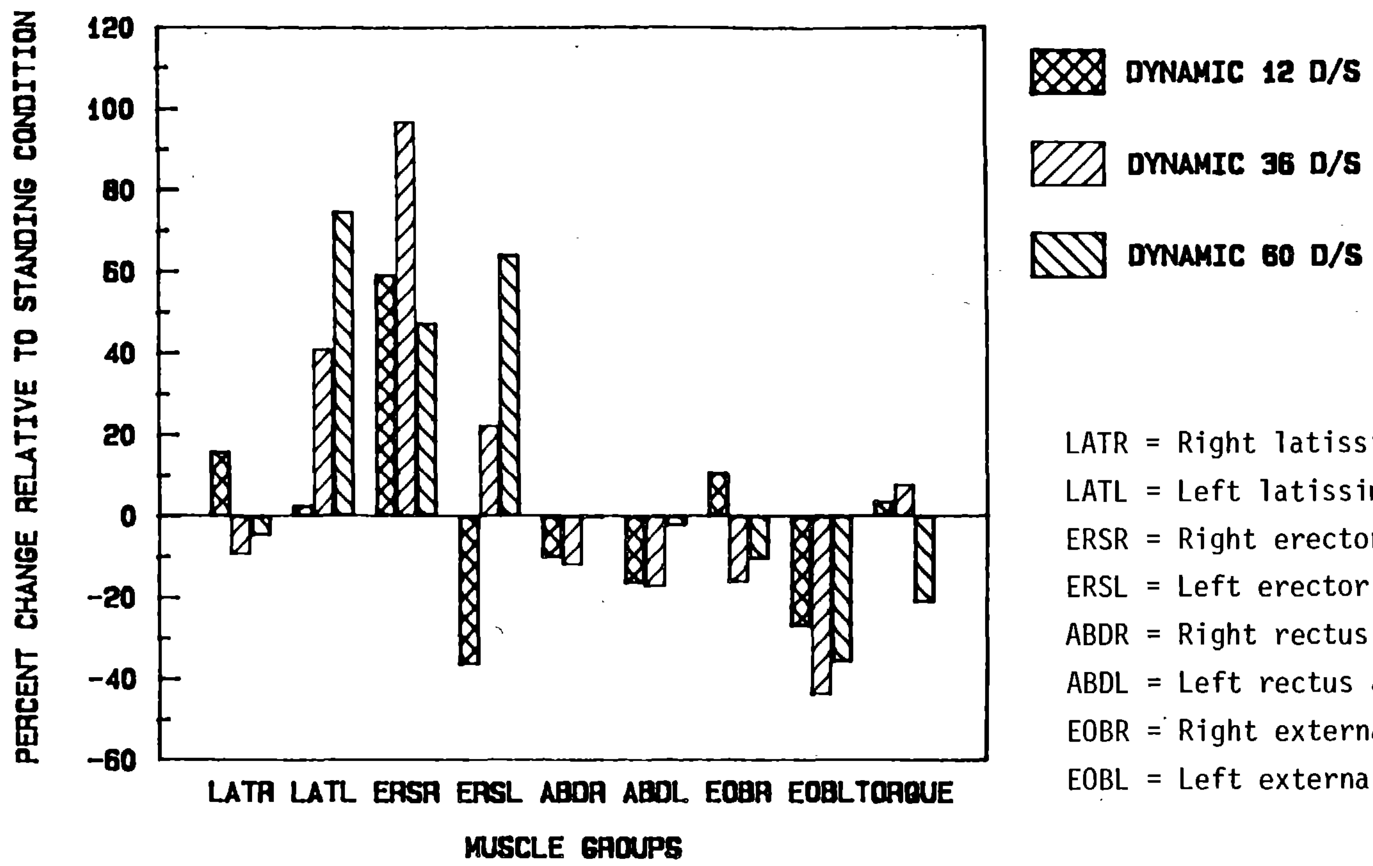


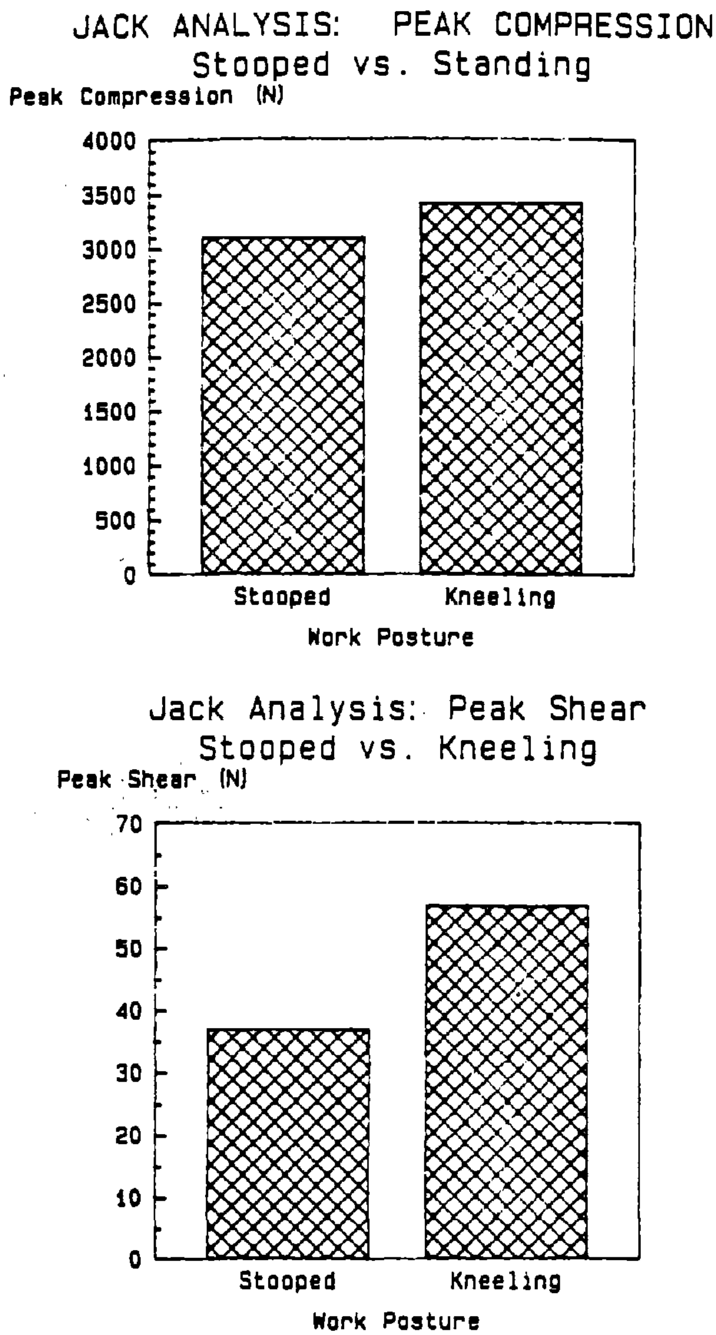
FIGURE 8—1: COMPARISON OF PEAK EMG WHILE OPERATING A SIMULATED JACK IN A KNEELING VERSUS STOOPED POSTURE (STATIC)

PERCENT CHANGE IN PEAK EMG IN KNEELING POSTURE RELATIVE TO STOOPED POSTURE (DYNAMIC)



LATR = Right latissimus dorsi
LATL = Left latissimus dorsi
ERSR = Right erector spinae
ERSL = Left erector spinae
ABDR = Right rectus abdominus
ABDL = Left rectus abdominus
EOBR = Right external oblique
EOBL = Left external oblique

FIGURE 8–2: COMPARISON OF PEAK EMG WHILE OPERATING A SIMULATED JACK IN A KNEELING VERSUS A STOOPED POSTURE (DYNAMIC)



N = Newton

FIGURE 8-3: ESTIMATED PEAK COMPRESSION AND PEAK SHEAR WHILE OPERATING THE SIMULATED JACK so that force generation by the arms is maximized. This is attained by adjusting the leg position so that the center of gravity of the body is directly above the jack handle.

Next, the activity of the trunk muscles was investigated during the performance of the jacking task. This study clearly shows that the back muscles are far more active in the kneeling posture compared to the stooped posture. In fact, in the kneeling posture the back muscles may produce up to five times the force compared with stooped postures. When this information is considered in concert with the fact that the abdominal muscles vary, at a lower level, in their force production under these conditions, we can conclude that the trunk is loaded much more asymmetrically when a worker assumes a kneeling posture. This is highly significant since asymmetric trunk loading has been identified as a significant occupational risk factor.

The trunk muscle activities should also be considered in conjunction with the amount of torque production that was generated in each work posture. Far more trunk muscle force was generated in the kneeling posture, yet torque production was generally greater in the stooped posture. Thus, in order to exert the same amount of force on the jack, the trunk muscles when stooped must work at a much greater percentage of their maximum capacity. Finally, the predictions of forces upon the lumbar spine favor the standing posture. Both the compressive and shear forces on the spine were substantially greater when the subject worked in the kneeling posture while performing the jacking task. This is also particularly interesting considering the fact that workers are less able to produce force on the jack handle in this posture.

All of these indicators agree as to the preferred posture in which to use this tool. It seems reasonable that if workers are kneeling, they can not move their center of gravity over the tool as easily as when they are in a stooped posture. Thus, they can exert less force upon the handle. If a person is kneeling, the spine must also be further from the jack handle. Thus, there is a greater moment imposed on the spine and greater trunk muscle forces must be exerted to perform the task. These increased muscle forces cause greater internal forces within the trunk and result in an increase in spine compression and shear forces. Thus, this biomechanical logic points to the fact that the stooped position should be used to operate this tool.

These findings agree with conventional biomechanical logic. One may wonder if it is necessary to perform a biomechanical experiment to confirm this logic. Most biomechanical experts agree that it is absolutely necessary to experimentally confirm this reasoning. This is true because the body is such a complex mechanism and, often times, the response of various body structures and muscles defies conventional wisdom.

CHAPTER 9: WRENCH EXPERIMENT

INTRODUCTION

Wrenches represent tools that are used for a variety of tasks. The epidemiological portion of this study indicates that the risk of a trunk-exertion injury in coal mining is substantial. As a matter of fact, this type of injury accounts for almost three times the number of days lost compared with this type of injury due to scaling bar use.

The task and ergonomic analyses have revealed that the main trunk-loading factor when using the wrench appears to be the posture of the trunk during force application with the tool. The task analysis identified four elements of task performance for this tool. The actual exertions are due to the push and pull components of the tool usage. These posture-dependent components were identified by the ergonomic analysis as elements that may relate to the back-exertion injury. Thus, the focus of this investigation will be the posture that the worker assumes during the exertion. Since the posture of the worker is usually a function of the task height, this experiment will focus on a "worst case" scenario for wrench use, which is working at ground level. As in the previous experiments, this study will investigate the loading of the internal structures (trunk muscles) via EMG in response to the experimental conditions.

METHODS

Subjects

Three male subjects between the ages of 21 and 25 volunteered their services for this experiment. The mean height was 179.2 cm (s=6.6 cm) and the mean weight was 73.3 kg (s=4.2 kg). All subjects were healthy and had no previous history of musculoskeletal problems.

Experimental Design

The experiment was designed to test two independent variables. The subject's work posture was either stooped or kneeling. Three types of exertions were tested. The subject was instructed either to push, pull, or work with the wrench in a center position. This last condition required the left arm to pull and the right arm to push. Subjects participated in all cells of a randomized block design. The experiment was blocked on subjects and within each block the order of the six conditions was randomized.

Six dependent measures were collected. These were the EMG signals from 6 muscles responsible for stabilizing the trunk. These muscles were the left and right latissimus dorsi, left and right erector spinae, and left and right rectus abdominus. Additional torque data was collected from a dynamometer; however, due to a confounding of these torque values with wrench impacts, the data could not be analyzed.

Apparatus

The experiment was conducted in the simulated mine described in previous experiments in this report. The dynamometer was bolted to the side rail along the floor of the apparatus. A 19 mm hex head bolt was tapped into a plate mounted on the end of the dynamometer. The net result of this mounting positioned the head of the bolt away from the subject with the shaft of the bolt parallel to the floor. The head of the bolt required a 38 mm diameter wrench. The wrench weighed 1.08 kg and was 48.25 mm long. The length of the moment arm available to the subject was 46.0 mm.

Procedure

Upon entering the laboratory, subjects were given a verbal description of the experimental task. After measuring the subject's height and weight, their muscles were isolated for electromyography. The skin was prepared using the procedure described in previous experiments in this report. Following the placement of the bipolar electrodes, each site was checked for conductivity.

Once acceptable values were obtained, the electrode placements were checked using functional muscle testing. Each muscle's electrodes were connected to a preamplifier that was worn on a belt. Each preamplifier was wired to an amplifier and an integrater. Here the signal was rectified and put through an rms integration. The signal from each muscle was then passed through an analog to digital converter and into the computer for storage and subsequent analysis. Each subject was also equipped with a mining caplamp, hardhat, and knee protection.

The postures used in this experiment were selected due to their frequent use when laying railroad track in underground coal mines. The subjects either assumed a stooped position over the dynamometer or a kneeling position just behind the dynamometer. These postures and the laboratory setup are illustrated in Figures 9-1 and 9-2. The center exertion had the wrench positioned with a vertical orientation. The pull and the push exertions had the wrench positioned 50° and 40° from the vertical, respectively.

During testing, subjects were instructed as to which posture they were to use and which exertion to perform. All exertions were instructed to be maximal efforts. Subjects were asked to slowly develop the maximal exertions and hold for two seconds. EMG data were collected during the entire period; although, only the steady-state maximal exertions were used in the analysis.

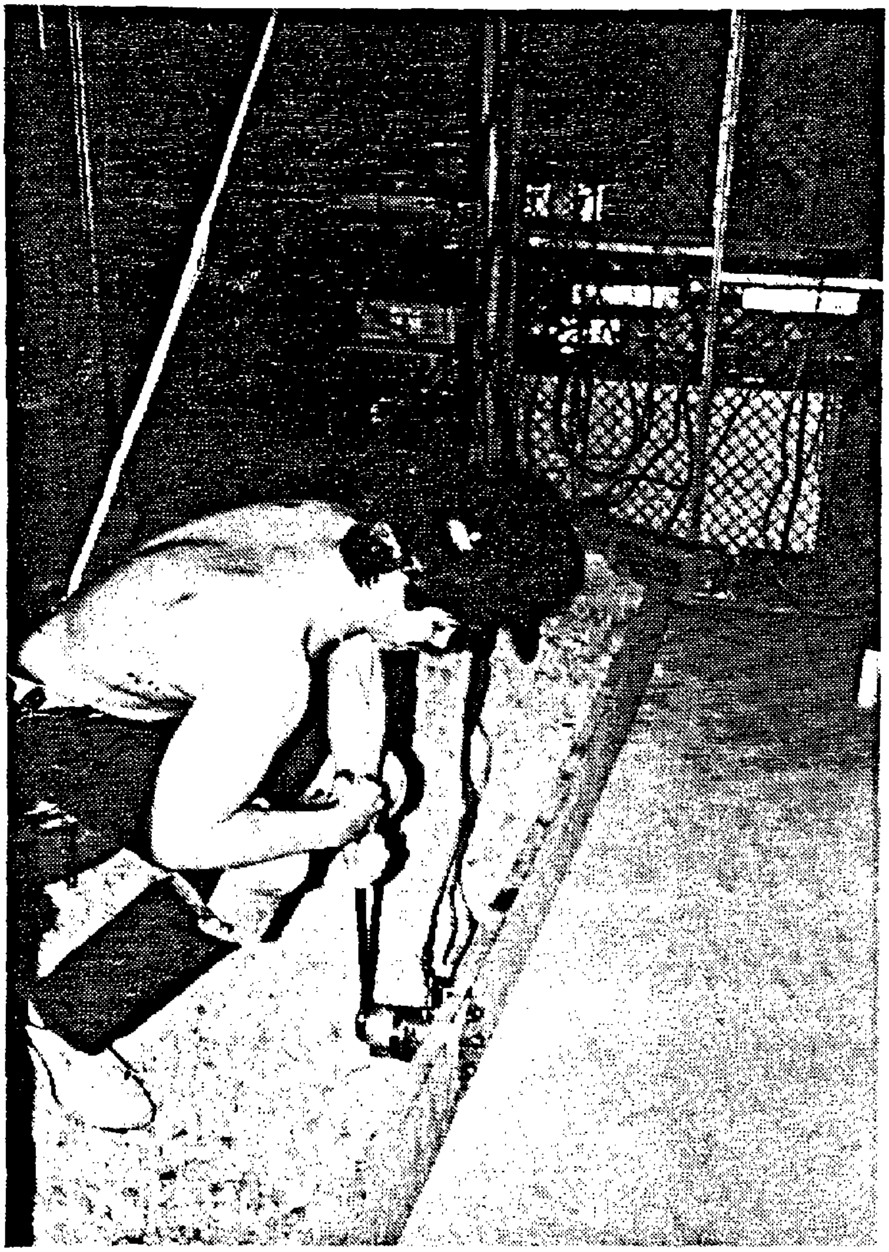


FIGURE 9–1: EXPERIMENTAL SETUP SHOWING SUBJECT IN PULLING POSITION

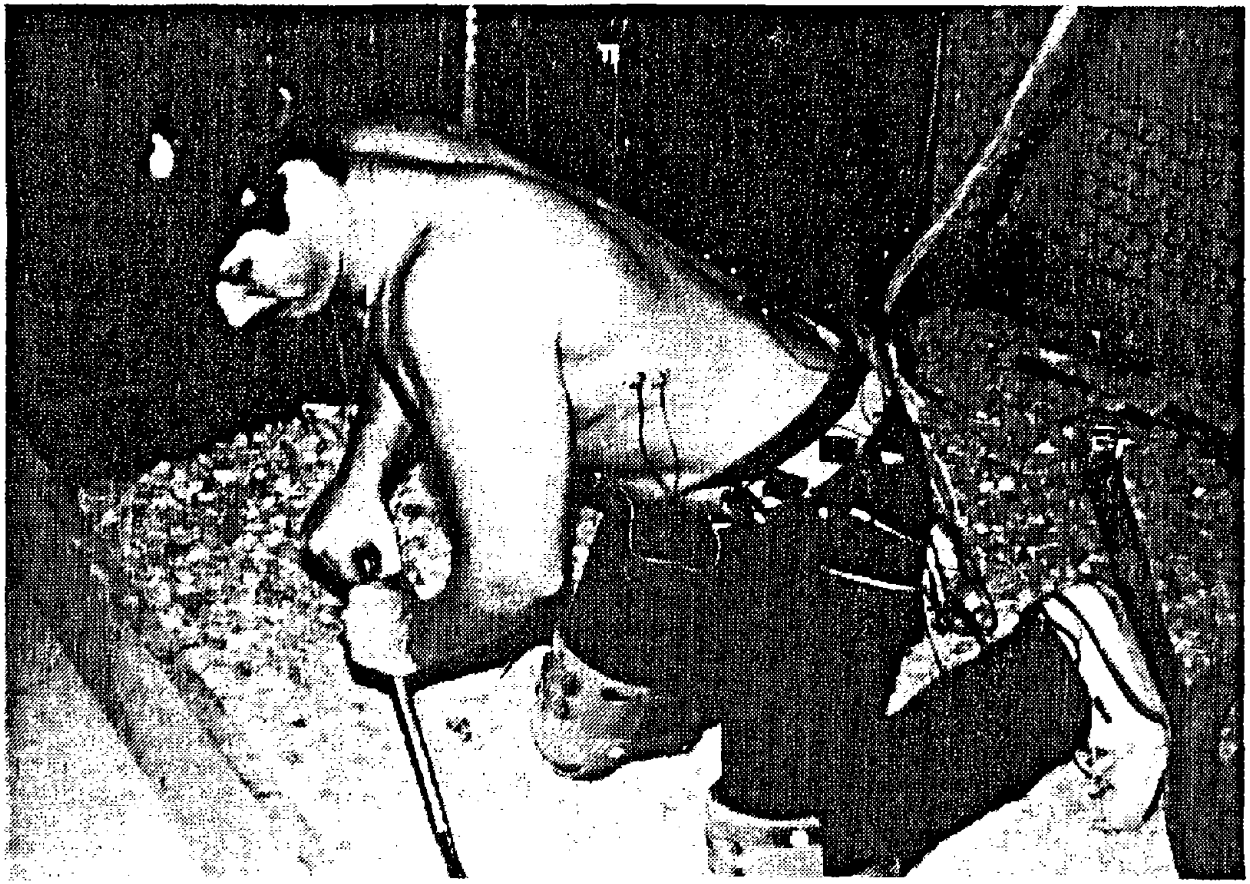


FIGURE 9–2: Experimental set up showing pushing posture

RESULTS

The objective of this study was to investigate the risk factors associated with low-back disorders during the use of the wrench in underground mining. The risk factors, identified via the task analyses, consisted of the posture of the worker during the use of the tool and the type of exertion used to apply force to the tool.

It is well-established that when kneeling or stooped-over greater torque can be applied to a wrench with a pull compared to a push or a center position type of exertion. It is also known that greater torque can be exerted if the feet are allowed to be used to assist in the exertion. Thus, the stooped-over posture increases the available torque compared to the kneeling position since the legs can be used to help develop force, particularly when pulling. This trend is also true with the push exertion as evidenced from the jack analysis.

When the response of the trunk muscles was observed, several trends were clear for all subjects. First, the kneeling posture generally produced greater trunk muscle force compared with the stooped posture. This is particularly significant considering that less force can be applied to the tool in the kneeling posture. Also, greater preloading was noted in back muscles while subjects were in the kneeling position prior to force exertion.

Second, pushing involved the activation of fewer trunk muscles but caused more asymmetry between trunk muscles compared to pulling. More symmetric loadings were observed when subjects exerted force in the center position of the wrench.

Third, interactions between posture and exertion are apparent between trials. For example, the kneeling and pushing conditions resulted in greater total muscle force among all muscles compared with stooping and pushing. Similar patterns resulted when the pulling interaction with posture was considered. An example of these trends for a particular subject can be observed in the plots of muscle force activities while in the various positions shown in Figures 9-3 through 9-7.

The muscle force activities were also used to compute peak forces acting upon the spine of the subject. A model developed by Reilly and Marras (1987) was used to compute the compression and shear forces acting on the lumbar spine as a function of the experimental conditions. The compression estimates were statistically evaluated for the group of subjects to identify significant effects. The analysis indicated that both posture ($F=19.60$, d.f.=1, $P<0.05$) and exertion ($F=20.54$, d.f.=2, $p<0.05$) exhibited a significant effect upon spine compression. The nature of these effects is shown in Figure 9-8. This figure shows that the kneeling posture consistently causes more compression upon the spine than the stooped posture. The figure also shows that the pull exertion results in the greatest compression, whereas the push exertion results in the lowest compression values. It is also noteworthy to observe that the compression resulting from the kneeling-pull condition was over 57% greater than in the stooped-pull condition. This situation represents the greatest difference between conditions.

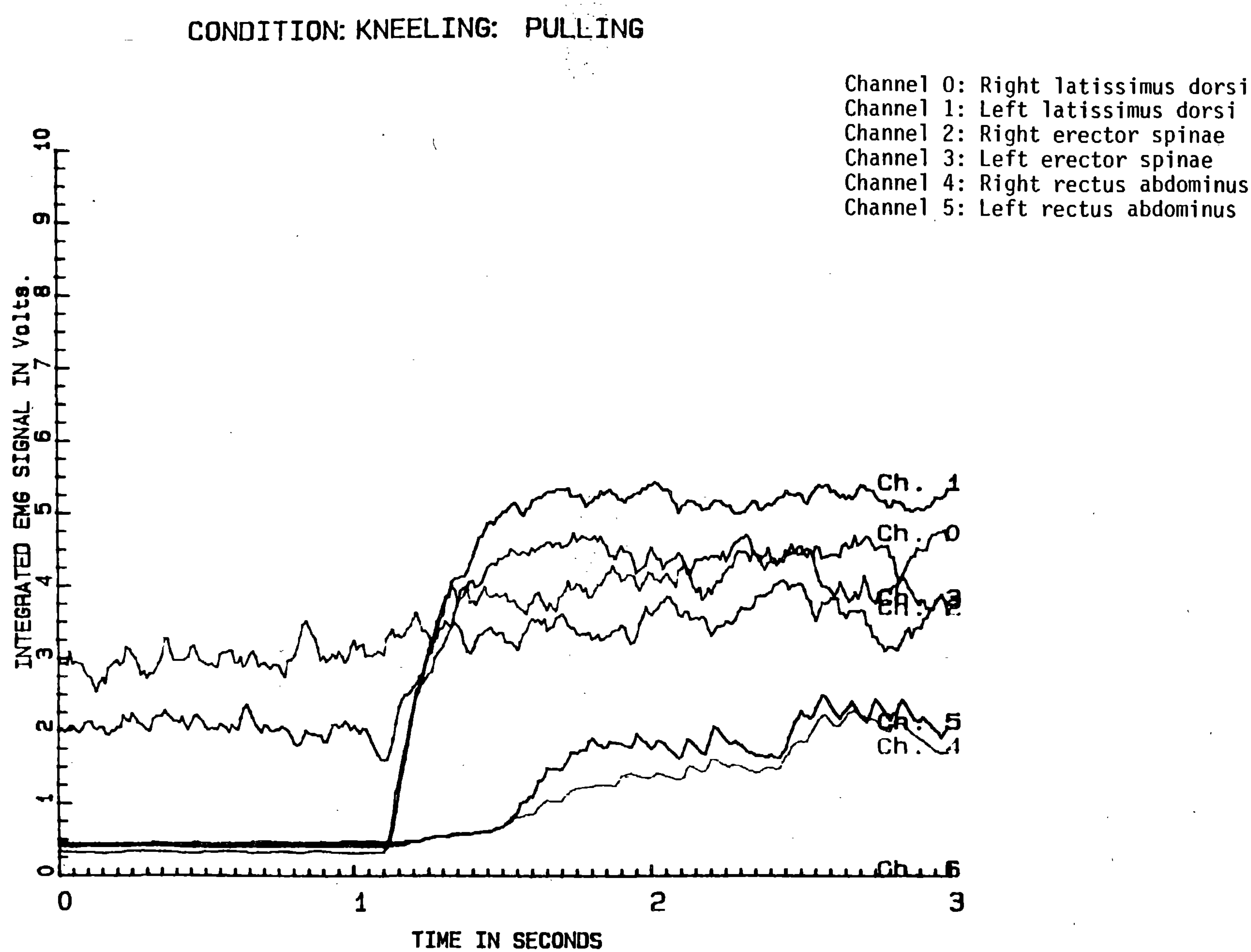


FIGURE 9—3: PULLING WRENCH IN KNEELING POSTURE

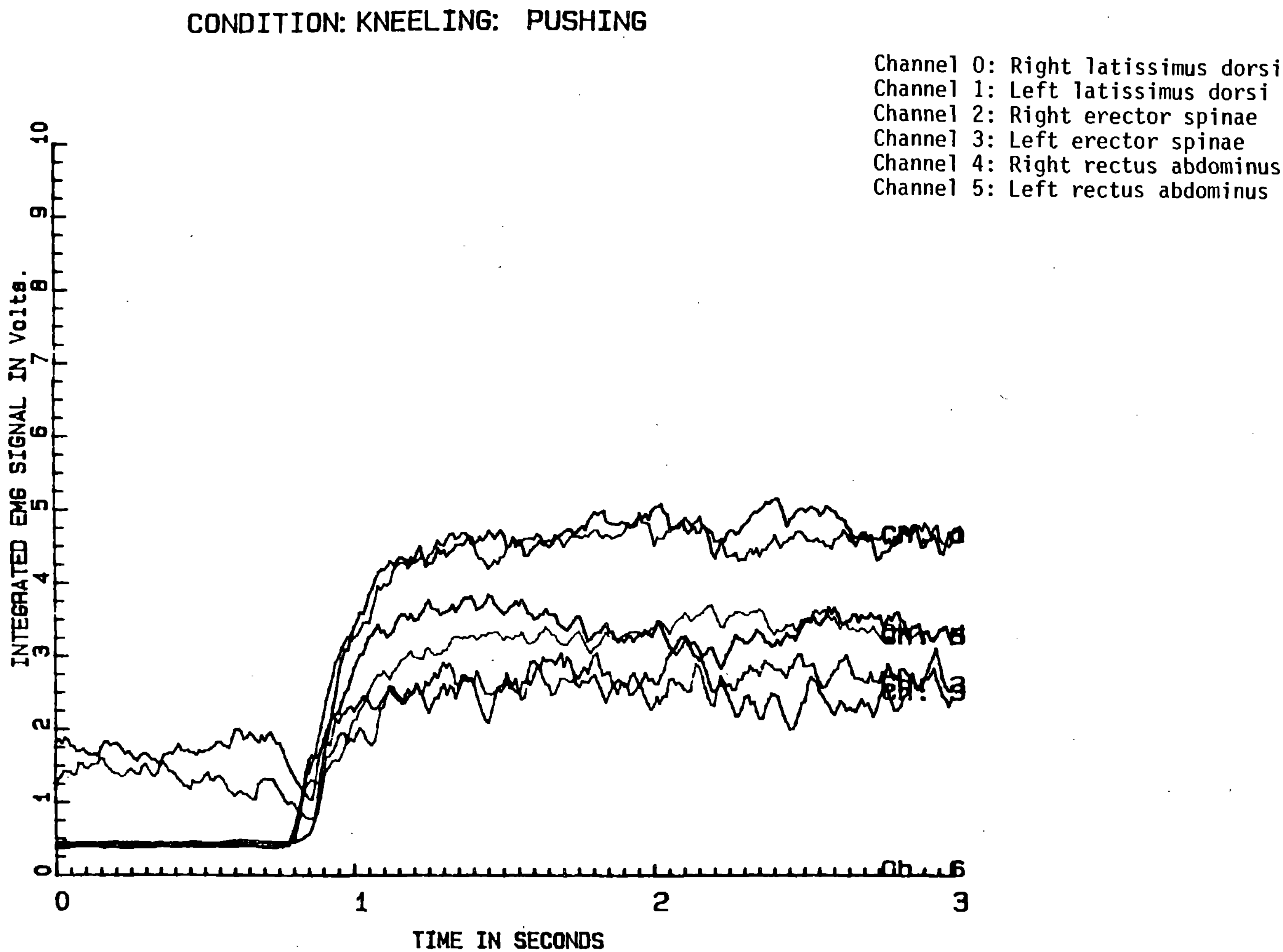


FIGURE 9—4: PUSHING WRENCH IN KNEELING POSTURE

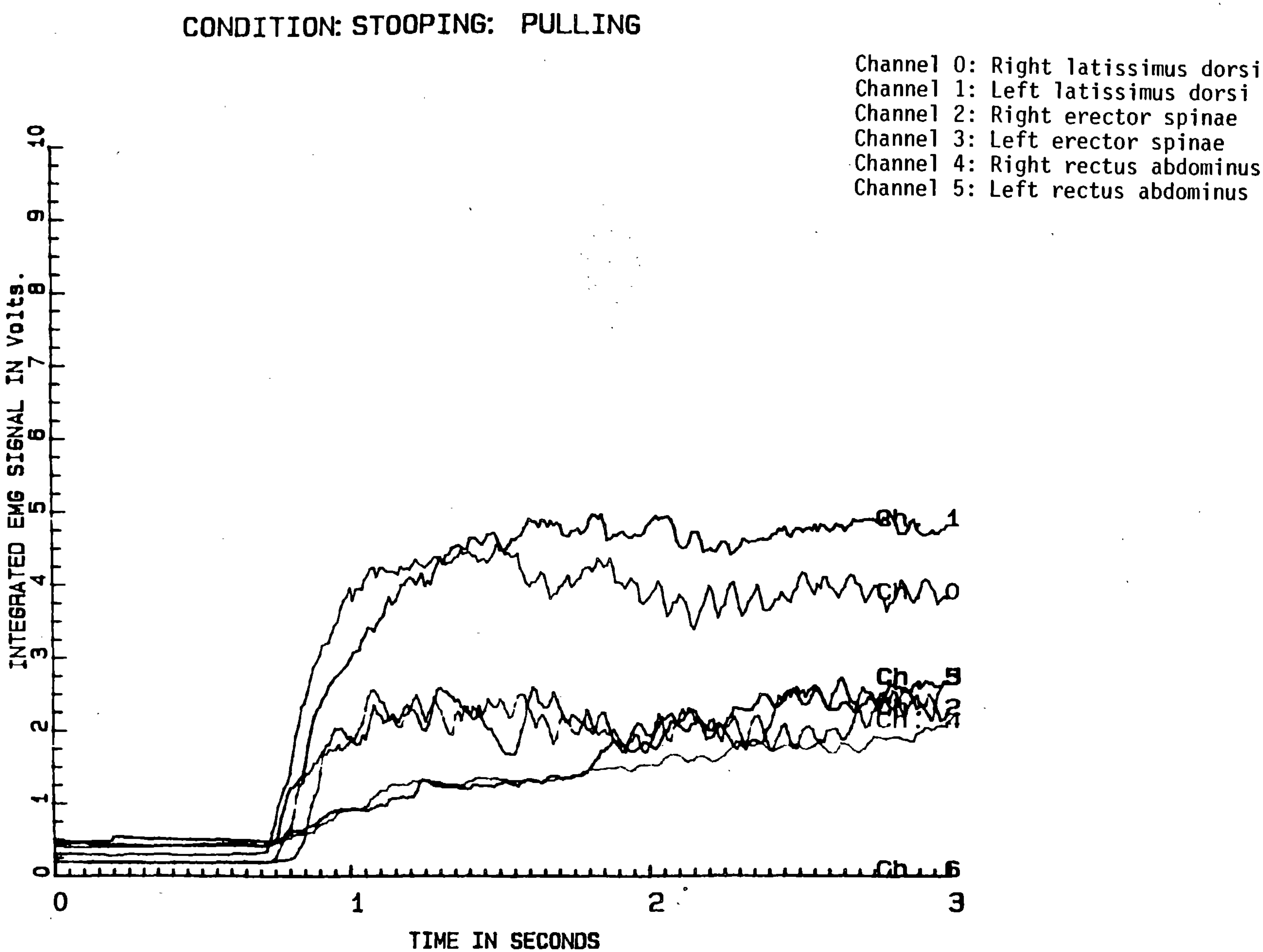


FIGURE 9—5: PULLING WRENCH IN STOOPED POSTURE

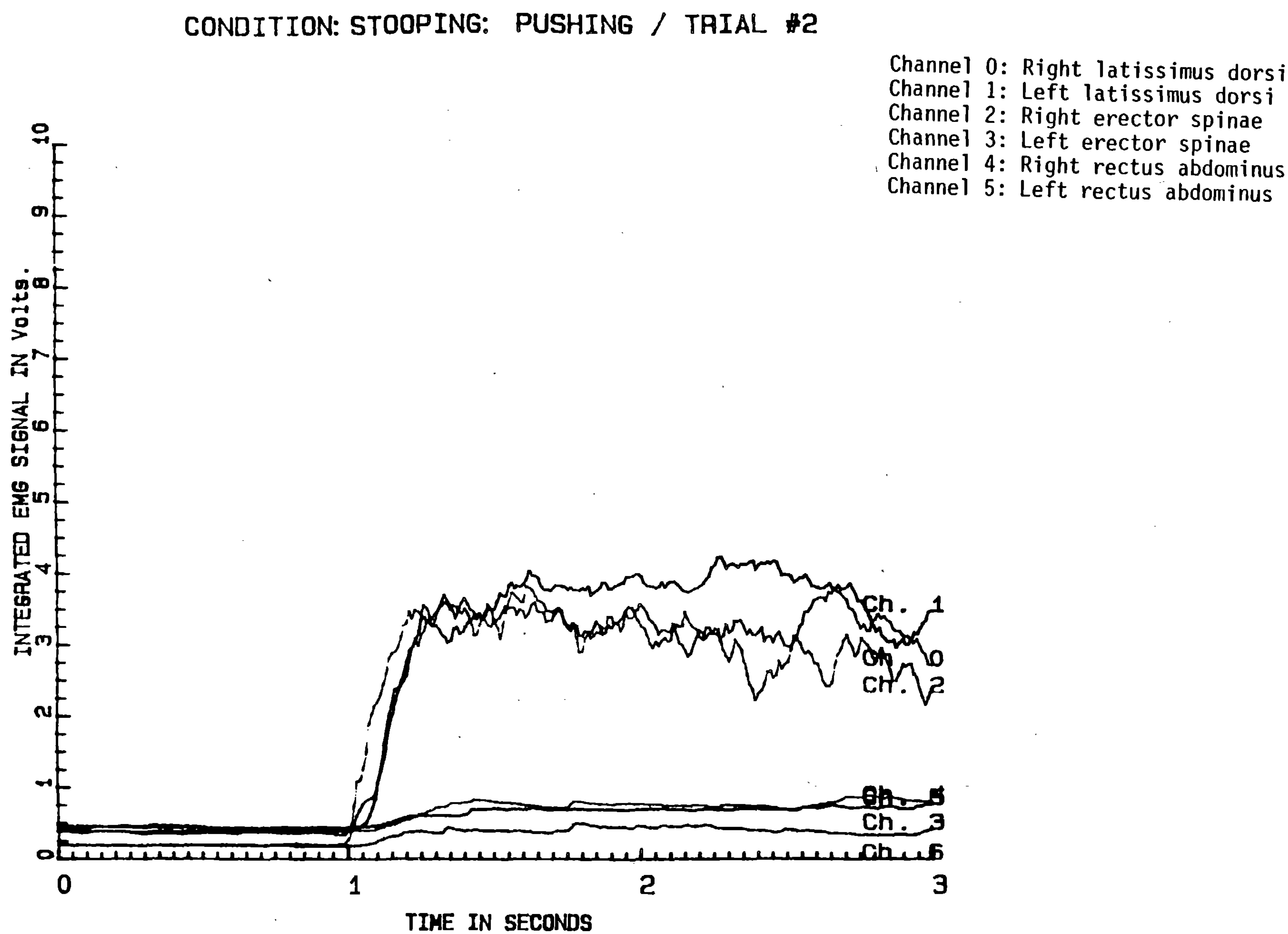


FIGURE 9–6: PUSHING WRENCH IN STOOPED POSTURE

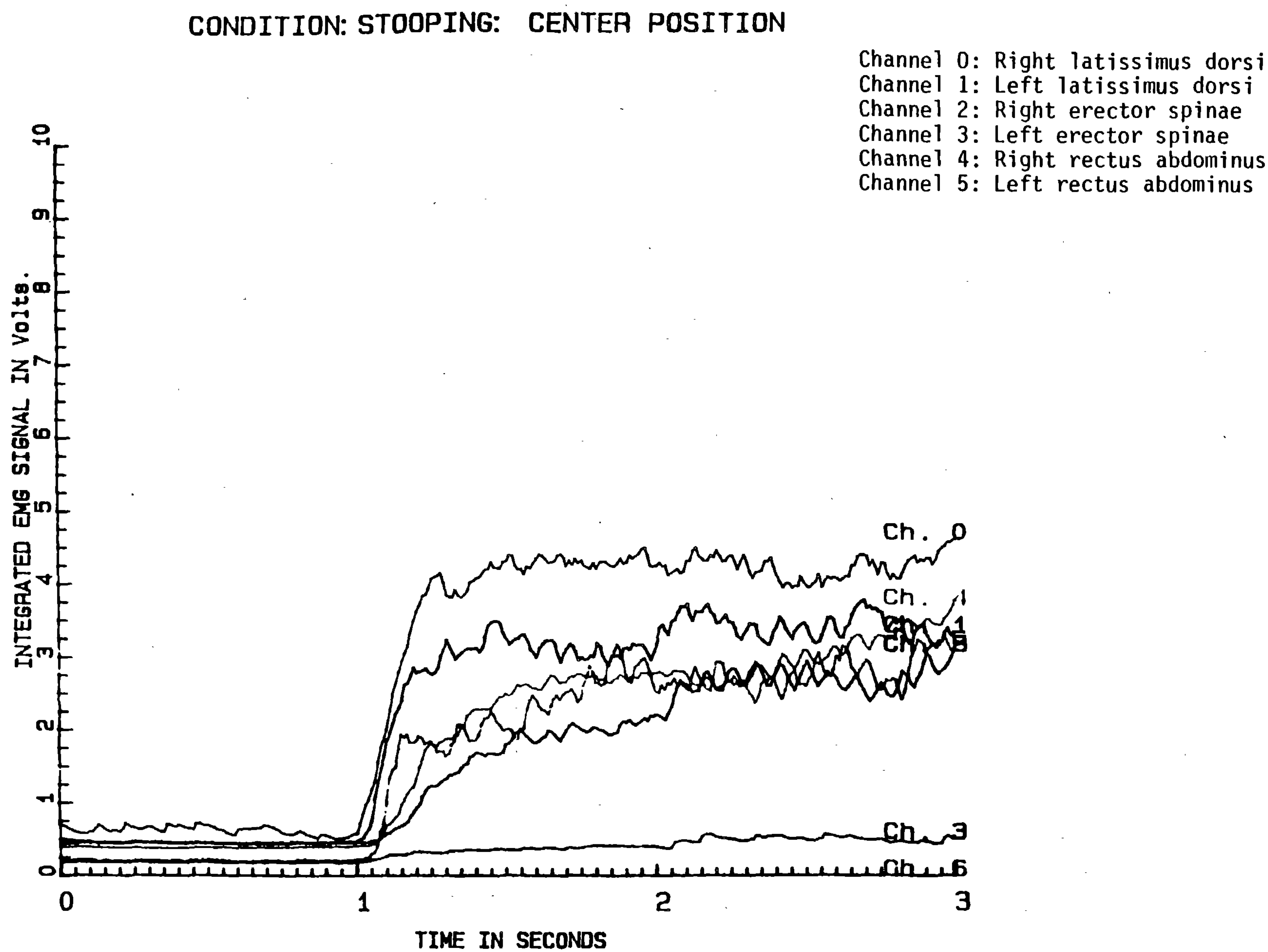
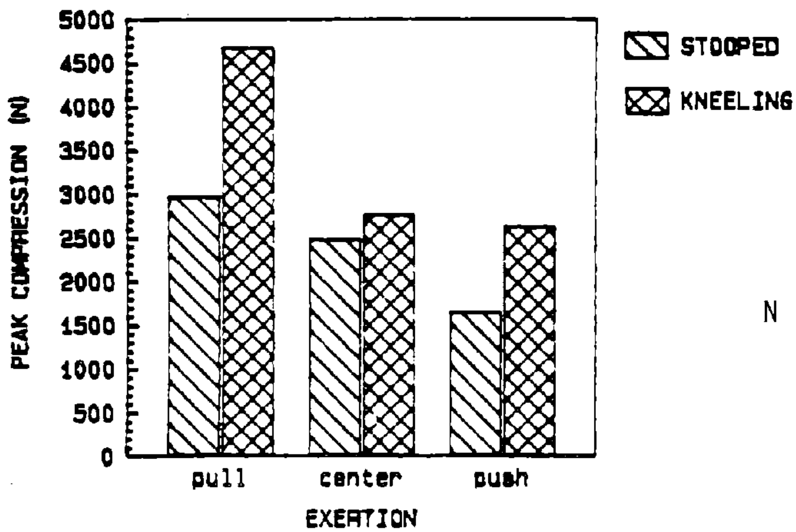


FIGURE 9—7: STOOPED POSTURE WITH WRENCH IN THE CENTER

WRENCH COMPRESSION AND SHEAR ANALYSIS

Part I: Peak Compression



N = Newton

WRENCH COMPRESSION AND SHEAR ANALYSIS
Part II: Peak Shear

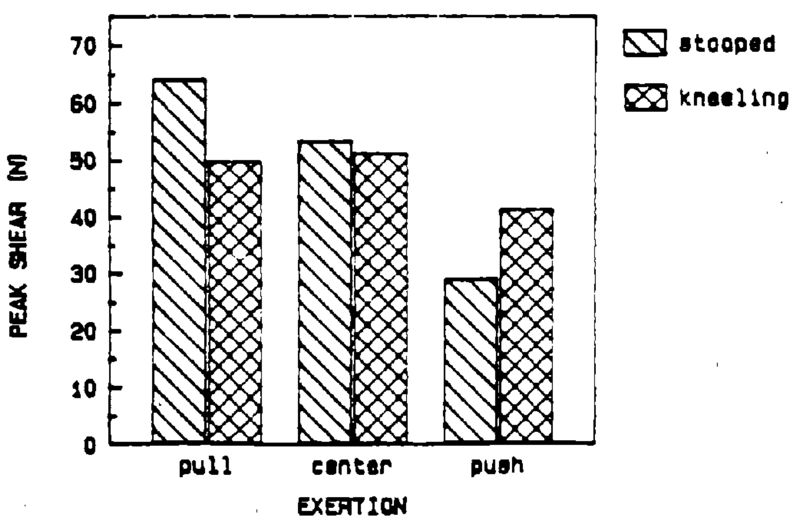


FIGURE 9-8: ESTIMATED COMPRESSION AND SHEAR FORCES AT THE L5/S1 JUNCTURE IN THE SPINE

Finally, differences between predicted spine shear forces were considered for the various conditions and are also shown in Figure 9-8. This figure indicates an interaction between posture and exertion. While in the kneeling posture, the computed spine shear is lower than in the stooped posture for pulling; whereas, for the push exertion condition, the stooped posture indicates lower shear. It should also be noted that the magnitude of these forces is much lower than for compression.

DISCUSSION

When the results of the wrench experiment are considered collectively, it is clear that the stooped-pull position is the preferred position from which to use a wrench so that the risk of back injury is reduced. This is true for several reasons.

First, when the trunk muscle forces are considered it is clear that kneeling requires greater trunk muscle forces. This is probably due to the fact that the lower extremity can not help produce substantial torque by providing stable ground reaction forces. Pushing also resulted in greater asymmetric activity of the trunk muscles, which is also a known risk factor. There also appears to be greater static loading on the back muscles when a worker is in a kneeling position. An increase in back muscle activity is evident even when no tool exertion is occurring. This implies that a static load is present on the back just in maintaining this posture. This static posture is a known risk factor. The muscle strength and endurance is decreased since there is a reduced capacity for the blood to exchange nutrients and waste products with muscles under static overload conditions.

Second, the predicted compression and shear forces on the spine show that the stooped posture is preferable to the kneeling posture. The peak compression values obtained using the Riley and Marras (1987) model for the kneeling pull exertion exceed the action limit recommended by NIOSH (1981). The stooped-pull posture had similar compression values to the other cells in the experimental design. Thus, while the compression is greater in this later pull condition compared to the other conditions, the difference is small and must be considered in conjunction with the fact that the torque exertion capability is much greater in the pull position (Chaffin and Andersson, 1984).

In this experiment, the subjects were asked to exert maximal force upon the wrench. Thus, as previously mentioned, the maximal force one can exert in the pull position would be greater than in the other positions. If the results are interpreted so that the relative muscle force and spine forces are monitored for a given unit of torque production on the wrench, it would be clear that the stooped-pull exertion conditions would produce the least amount of muscle force and spine force to produce a given amount of work. Hence, the biomechanical cost to the body is less in the stooped-pull position and the capability is greatest. This is particularly significant considering the requirements of the wrench use task (i.e. the required force does not change as a function of the worker position to produce the desired result).

Finally, the safety parameters of tool use, other than back injury risk, should be considered. The epidemiology data indicate that this tool also has a capacity to produce acute injuries, such as arm cuts and breaks. The task analyses and ergonomic assessments indicated that these injuries represent collisions of the hands with the object being worked on with the wrench. In other words, workers are hitting their hands and knuckles on the object when they reach the end of the wrench range of motion. This type of injury also would be minimized if the worker pulled upon the wrench instead of pushing down upon the tool. There is not a solid object, like a track rail, against which a subject can hit his hands when he pulls up. Of course, one must consider seam height when suggesting such a solution. If the seam height is too low, the risk of hitting the worker's head may increase if he were in this position. Thus, one would trade one injury scenario for another. These issues must be kept in mind when considering the optimum positions for using this tool underground.

CHAPTER 10: SUMMARY AND CONCLUSIONS

This study has accomplished several goals which serve to facilitate the understanding of how the design and method of use of underground mining hand tools is related to the risk of both acute and cumulative trauma disorders in the workplace.

First, the epidemiological analysis has identified those tools that are associated with the greatest risk of injury in both the coal and metal-nonmetal underground mining industries. In this study, risk was defined in terms of both frequency and days lost. Using either criteria, it is apparent that the scaling bar was associated with the greatest risk of injury in the coal mining industry. This was followed by the jack, pry bar, hammer/axe, and pneumatic drill. The remaining tools were associated with a minor degree of risk. The risk in the metal-nonmetal industry was quite different. The vast majority of risk (about 85 percent) was associated with the use of two tools: the jackleg drill and the scaling bar. Thus, this study has identified the specific tools that have the greatest potential for injury and has quantified the relative risk associated with each. The epidemiological analysis has also, for the first time, described the risk "sequence of events" that occur with each tool. These events include the part of body injured, the type of accident, the nature of injury, and the type of tool. Conditional injury probabilities were used to identify those sequences that are related to significant problem areas.

Second, the accident sequence information was used to guide the field study. The field visits documented the use of the tools in the working environment. The sequence information was used as a means to focus the field observations and subject interviews so that the high risk tasks were focused upon.

Third, the data gathered in the field study were evaluated by way of a task analysis. This task analysis "broke down" the task of using each tool into distinct, unique, components that could be quantified. The goal of this procedure was to identify different methods of tool use and document the biomechanical position of each significant portion of the body. Furthermore, this procedure permitted one to focus upon the part of the body which was most at risk (identified through the epidemiological analysis).

Fourth, an ergonomic analysis was conducted. This analysis was performed by comparing the biomechanical position information (derived from the task analysis) with general ergonomic principles, knowledge, and recommendations. Also, other information collected during the field observation study (i.e. worker opinion, environmental conditions, space restrictions, etc.) were considered and evaluated during this phase of the research.

Next, hypotheses were generated based upon the ergonomic analyses. These hypotheses collectively considered the data generated from the field study, the task analysis, and the ergonomic analysis in order to identify the key problems associated with the injury sequence specified in the epidemiological analysis. These hypotheses not only identified the root of the problem but identified alternative solutions to remedy the problem.

Finally, several laboratory studies were performed to investigate these hypotheses. Most of the injury sequences indicated that the injury was of a musculoskeletal nature. Specifically, these injuries involved the back. Thus, the focus of the laboratory study was to investigate the status of the internal force-development structures within the back. The tools investigated in these studies included the jackleg drill, the scaling bar, wrench, and the jack. The method of using the tool and tool design issues, and their relevance to internal force development in the trunk were discussed. This process led to the development of recommendations and a discussion of the trade-offs associated with these recommendations.

This study represents the first comprehensive investigation into handtool injuries in the underground mining environment. The investigation process started by taking a wide view of the problem and then systematically narrowing the focus to the issues that offered the largest solution impact on the problem.

This project was an ambitious task that was limited only by available resources. Even though this study has identified and even tested many of the ergonomic and biomechanical issues associated with mining handtool usage, it should be considered an initial effort that just began to identify the issues associated with handtool injuries in the mining environment. It is the opinion of these researchers that the number of questions raised is at least equal to the number of questions answered by this study.

There are many more issues relative to handtool use that need to be addressed before the risk associated with handtool use in underground mining is considered reasonable. For example, it is believed that the data base used to evaluate handtool injuries has severely underestimated the risk of cumulative trauma disorders such as carpal tunnel syndrome and tenosynovitis. Thus, better surveillance and reporting techniques are needed so that the sequence of components associated with these injuries are identified and the ergonomic problems can be addressed. Also, more laboratory studies are needed so that factors associated with injury sequences other than the primary injury sequence can be explored.

Through efforts such as the present study, a safer and more productive work environment can hopefully be created. The benefits of a successful ergonomically designed workplace will include less time off work, fewer accidents, a reduction in costs, greater production, and an increase in the quality of life for the worker. These benefits are the goals of ergonomics.

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