Task-specific postures in low-seam underground coal mining

Susan M. Moore*, Jonisha P. Pollard, Mary Ellen Nelson

Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Office of Mine Safety and Health Research, Human Factors Branch, United States

ABSTRACT

The objective of this study was to determine low-seam mine worker exposure to various postures as they pertain to job classifications and job tasks. Sixty-four mine workers from four low-seam coal mines participated. The mine workers reported the tasks they were required to complete and the two postures they used most frequently to perform them. They were provided with a schematic of postures from which to select. The two postures reported most frequently were identified for each task along with the job classification of the workers performing the tasks. Of the 18 tasks reported, over two thirds were performed by at least two different job classifications and over one third were performed by four or more job classifications. Across tasks, the postures used appeared to vary greatly. However, when grouped by job classification, the most frequently reported posture across all job classifications was kneeling near full flexion. Operating the continuous miner was associated with frequent squatting and was likely used because it affords great mobility, allowing operators to move quickly to avoid hazards. However, for environments with a restricted vertical height such as low-seam mining, the authors recommend squatting be avoided as data demonstrates that large amounts of femoral rollback and high muscle activity for the extensors when performing lateral lifts in this posture. Kneeling near full flexion was reported as the most frequently used posture by all job classifications and was likely due to the fact that it requires the least amount of muscle activity to maintain and has reduced pressures at the knee. However, the authors recommend this posture be avoided when performing lateral lifting tasks. Like squatting, kneeling near full flexion results in increased femoral rollback and may increase the stresses applied to the meniscus. Unlike lateral lifting, maintaining a static posture results in knee loading and muscle activity such that the mine worker *should* consider kneeling near full flexion and sitting on their heels. Although kneeling near full flexion is associated with injuries, there are benefits to this posture that are realized when statically kneeling (minimal muscle activity, allows worker to maintain an upright torso in low heights, and decreased loading at the knee). However, cartilage is avascular and nourished by synovial fluid. Therefore, one should frequently rotate between postures, assuming a more upright kneeling posture when possible and frequently fully flexing and extending the knee allowing nutrients to the cartilage.

Relevance to industry: In 2009, over one fourth of underground coal mines that produced coal in the United States were considered low seam with an average working height of <109.2 cm (MSHA, 2009) restricting workers to their knees. Data exists regarding the biomechanical implications of kneeling postures and demonstrates the possibility of detrimental consequences to varying degrees for each posture. With each posture posing a different level of exposure to musculoskeletal disorder risk factors, it is essential to determine the postures mine workers use to perform their job tasks and how their postural options are restricted by the low-seam underground mining environment.

1. Introduction

In 2009, 532 underground coal mines produced a total of 330.8 million tons of coal (MSHA, 2009). Of these mines, 148 (28%) were considered low seam with a seam height of less than 109.2 cm and produced 19.1 million tons of coal. For economic reasons, the seam height of the coal corresponds with the working height (from mine floor to mine roof) of the mine. Thus, at least 6% of underground coal produced in the United States in 2009 came from a mine where workers were restricted.

Individuals who work in underground coal mines face a variety of challenges. Many studies have demonstrated that low-seam

* Corresponding author. 626 Cochrans Mill Road, PO Box 18070, Pittsburgh, PA 15236, United States. Tel.: +1 412 386 6613.

E-mail address: SMMoore@cdc.gov (S.M. Moore).

mine workers suffer multiple forms of injury to the knee such as meniscal tears, osteoarthritis, ligament tears, and bursitis, or beat knee (Hodgson, 1975; McMillan and Nichols, 2005; Roantree, 1957; Sharrard and Liddell, 1962, 1963, 1965; Watkins et al., 1958). These injuries are likely attributed to the low working heights confining workers to kneeling and squatting postures which have both been associated with knee injuries (Baker et al., 2003; Coggon et al., 2000; Sharrard and Liddell, 1962, 1963, 1965).

Occupational knee injuries plague many industries and are not limited to mining. Many occupational exposures have been linked to the long term development of knee injuries. Worker position and motion causes the knee to be the most frequently injured lower extremity in all industries (US Bureau of Labor Statistics, 2009). Tibiofemoral osteoarthritis has been associated with the frequency of knee bending required at work, frequent squatting, side-knee bending, and sitting crossed legged, and frequent heavy lifting (Anderson and Felson, 1988; Tangtrakulwanich et al., 2006; Cooper et al., 1994). An association between kneeling and squatting has also been found in the prevalence of surgically treated meniscal injuries (Baker et al., 2003). The likelihood for developing patellofemoral osteoarthritis has been found to increase with kneeling, squatting and heavy lifting (Amin et al., 2008). Additionally, physically strenuous work and daily lifting of loads was found to increase the risk of knee pain in the working Finnish population (Miranda et al., 2002). In any setting, knee injuries can be extremely debilitating and effect one's quality of life. In fact, knee pain is quite persistent with 66% of people that report severe pain still suffering from this pain one year later (Miranda et al., 2002).

Recently, the National Institute for Occupational Safety and Health (NIOSH) investigated the muscle activity of the knee flexors and extensors, pressure applied to the knee, forces and moments at the knee, and the joint angles of the knee while subjects assumed a series of different kneeling and squatting postures (Gallagher et al., 2011; Mayton et al., 2010; NIOSH, 2008; Moore et al., 2009, 2010, 2010; NIOSH, 2011; Pollard, 2008, 2009; Pollard et al., 2011, 2010). For each parameter investigated, certain postures appeared to be more or less detrimental than others. However, the postures likely to be detrimental were not entirely consistent across the parameters investigated. Rather, a complex interaction was observed which suggests that postural rotation strategies are an important intervention to consider as a means for minimizing the negative impact of the various postures while maximizing their possible benefits.

Mine workers employ a variety of postures to complete their job duties. Each of these postures place very different demands on a workers' knee exposing them to different types of risk and exposure levels of these risk factors. In mining, the frequencies with which various restricted postures are used to perform work are unknown. Moreover, the postures selected are likely to depend on the task being completed. Thus, certain job classifications may be inclined to use only a select number of postures. Recent research conducted by NIOSH identified significant differences in the biomechanical demands of kneeling and squatting postures (Gallagher et al., 2011; Mayton et al., 2010; NIOSH, 2008; Moore et al., 2009, 2010; NIOSH, 2011; Pollard, 2008, 2009; Pollard et al., 2011, 2010). All of these postures would pose different levels of exposure to musculoskeletal disorder risk factors. To determine the risks for mine workers, it is essential to determine the postures they use to perform their job tasks and how their postural options are restricted by the low-seam underground mining environment. The objective of this study was to determine the postures routinely used by low-seam mine workers as they pertain to job classifications and job tasks.

2. Methods

Mine workers at four low-seam coal mines agreed to participate in this study. The working height at these mines at the time of data collection was 91.4 cm, 109.2 cm, 121.9 cm, and 137.2 cm (NOTE: The seam height, and thus the corresponding working height, of a mine fluctuates. All mines in the study were considered low-seam based on their average seam height. The working height of these mines during data collection restricted the mine workers to their knees throughout their entire shifts). All four mines were room-and-pillar mines with a continuous miner machine and one or two dual-boom roof-bolter machines.

A total of 64 mine workers were included in the study: beltman ($n = 2$), continuous miner operator ($n = 5$), section foreman ($n = 5$), mechanic ($n = 6$), mobile bridge operator ($n = 10$), shuttle car operator ($n = 6$), scoop operator ($n = 6$), roof-bolter operator ($n = 14$), and maintenance shift worker ($n = 10$). The mine workers (all male) self-reported their height (175 $\pm$ 9 cm), weight (83.1 $\pm$ 14.8 kg), age (37.3 $\pm$ 13.1 years), time in their job classification (8.0 $\pm$ 11.3 years), and time working in low-seam mines (8.3 $\pm$ 10.3 years). Mine workers wear numerous items on their mine belts (e.g., self-rescuers, cap lamp battery, tools). As these items contribute to the weight on the knees, the mine belts and items on them were weighed using a dial scale (5.1 $\pm$ 1.8 kg).

The mine workers were then asked to identify the various tasks they perform. A total of 18 tasks were identified (Table 1): hanging curtain, hanging cable, loading and unloading supplies, rock dusting, building stoppings, shoveling, mechanic duties, repairing equipment, advancing power load center, greasing equipment, changing continuous miner bits, moving or advancing belt, scooping faces, operating the roof bolter, operating the mobile bridge, operating the shuttle car, operating the continuous miner, and moving about the mine.

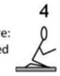
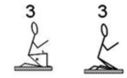
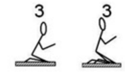
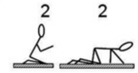
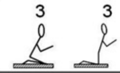
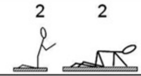
To aide with the usage of mine terminology the following definitions are provided:

- Rib – walls on the sides of an underground coal mine
- Roof – ceiling of an underground coal mine
- Return – a hallway in an underground coal mine
- Face – working wall where the coal is being cut to advance the mine (i.e., mine workers are cutting through this area to make the mine bigger and gather more coal)

Descriptions of the identified tasks are also provided:

- Hanging curtain. The mine worker will use a "spad gun" to drive a nail into the mine roof. The spad gun is a hand held type of hammer. The mine worker holds onto the shaft of the gun, and then pulls the middle portion outward. The worker then pushes or hits the middle back in, thereby driving a flat nail into the roof. Typically, the mine worker will then poke a hole through the curtain itself to hold it in place.
- Hanging cable. The power cables of many underground mining machines (e.g., continuous miner, roof bolter, etc.) are suspended from the mine roof to reduce their risk of being damaged by mobile equipment. The mine worker often hangs a hook from a roof bolt plate and then lifts the cable and hangs it on this hook. The roof bolter cable is lighter and easier to handle than the continuous miner cable. While it may only be necessary to hang a roof bolter cable when in a cross section where the shuttle car is operating, the continuous miner cable will be hung whenever it is in close proximity to the shuttle car. Shuttle cars are continually transporting coal from the mine face to the belt, so ensuring the continuous miner cable is off the ground is essential.

Table 1
This table shows the number of workers who reported performing each task, their job classifications, and the primary and secondary postures they use to perform each task (with the number of responders for each posture listed above the representative schematic).

Task	#of Workers	Job Classification Performing Task	Primary Posture	Secondary Posture
Hang Curtain	16	Shuttle Car Op Mechanic Foreman Scoop Op	7 	6 
Load and Unload Supplies	11	Foreman Scoop Op	7 	4 
Mechanic Duties	4	Mechanic Maintenance Shift	3 	2 
Advancing Power Load Center	14	Maintenance Shift Mechanic Foreman Scoop Op	5 	4 4 
Building Stoppings	14	Maintenance Shift Mechanic Foreman Scoop Op	9 	5 
Operate Mobile Bridge	9	Mobile Bridge Op	6 Unique Posture: Crossed Legged 4 	2 
Operate Continuous Miner	5	Continuous Miner Op Foreman	5 	2 
Grease Equipment	4	Maintenance Shift Mechanic	2 	N/A
Hanging Cable	13	Mechanic Shuttle Car Op	5 	3 3 
Changing Continuous Miner Bits	5	Maintenance Shift	3 3 	2 
Moving about Mine	4	Foreman	4 	3 
Moving or Advancing Belt	4	Maintenance Shift Mechanic	2 2 	N/A
Repair Equipment	4	Mechanic	3 3 	N/A
Rock Dusting	15	Shuttle Car Op Mechanic Foreman Scoop Op Beltman	7 	4 
Operating Roof Bolter	16	Roof Bolter Op Maintenance Shift Foreman Shuttle Car Op	14 	6 
Scooping Faces	5	Scoop Op	2 2 	N/A
Shoveling	9	Mechanic Foreman Shuttle Car Op Beltman	5 	N/A
Operating Shuttle Car	6	Shuttle Car Op	5 Unique Posture: Sitting back on seat in reclined position	N/A

- Loading and unloading supplies. Supplies are brought in on the rail haulage to each working area. From the end of the rail, supplies are delivered to differing areas within the mine using a piece of mobile equipment known as the scoop. Supplies are loaded into the bucket of the scoop and delivered to locations in the working area. It takes approximately 1 h for the scoop to be loaded with supplies and an additional hour for the supplies to be unloaded at their respective destinations. Typical supplies include: bags of rock dust (22.7 kg); buckets of continuous miner cutting head bits (~ 13.6 kg); crib blocks (~ 11.3 kg); packs of wedges (~ 9.1 kg); replacement parts, tools, or tool bags; and supplemental roof supports (e.g., straps, pie pans).
- Rock dusting. Pulverized limestone (rock dust) is used in underground coal mines to control explosive coal dust. Rock dusting may either be done by hand or with a machine. For machine dusting (e.g., trickle duster, swinger duster), the mine worker will empty bags of rock dust into a hopper and a fan blows dust down the return. For hand dusting, the mine worker typically cuts the bag of rock dust into two halves using a razor knife. The mine worker will then carry half of the bag (11.3 kg) in one arm while throwing the rock dust about the roof, ribs, and mine floor with the other hand or a hand shovel.
- Building stoppings. Stoppings are walls used to form air courses that facilitate removal of dust and methane gas from the mine. Similar to laying bricks, stoppings are built using large blocks that are bonded together using block bond. Block bond is a powder that is mixed with water in a bucket or lightweight, metal, square container. The bags of block bond weigh approximately 22.7 kg. While the blocks and block bond may be delivered by the scoop operator, many of the smaller supplies must be gathered by the mine worker as they are typically left at the last location a stopping was built. The mine worker must then dig a trench in the roof, floor, and into both ribs. Next, the mine worker places a plank of wood down in the floor trench and begins placing the blocks in the same staggered pattern used by brick layers. Half blocks are used to fill in the empty spaces by the rib and are created by breaking a block into two pieces with a hammer and chisel.
- Shoveling. The mine worker will typically have 2–3 different styles of shovel that they may use depending on the location of the coal buildup. The shovels are typically one with a long handle, one with a wide head and handle (~ 1 m in length) with a hand grip at the end, or a very narrow shovel for small locations. Some areas that commonly require shoveling are: under feeders, at and along the beltlines, along the ribs, frequently traveled areas such as main roadways, and on the continuous miner after a roof fall.
- Mechanic duties and repairing equipment. For mechanic duties or repairing equipment, carrying a large number of tools is necessary. This is accomplished by wearing tools on the belt itself or by using a tool pouch (~ 13.6 kg) which may be worn across the body, dragged, or carried. Replacement parts (e.g., motor, pulley) are typically delivered by other workers from the outside. However, these parts must still be transported to the work location which may be many feet from the delivery location. Furthermore, in order to access the parts being repaired/replaced, the mine worker may be reaching into the machine, next to the machine, on top of the machine, or under the machine. This mine worker may have assistance from a mechanic's helper or the operator of the machine that is down, or they may be working alone.
- Advancing power load center. The power load center provides electricity to power mining equipment and must be moved with the mobile equipment as the mine advances. The mine workers performing this task must shut off the power. The power load center must then be loaded onto the bucket of the scoop. Because the power load center is typically on wheels, this may be done by attaching the power load center to the scoop ram (mechanical arm in the bucket) which will then pull the power load center into the bucket of the scoop. The cables are often attached to the scoop and dragged to the new location. However, the mine workers drag, pull, and manipulate the cables often.
- Greasing equipment. When greasing equipment, the mine worker will carry the grease gun (i.e., mechanics would typically have it near their tool box). In order to have easier access to grease fittings, mines may attach tubes to the fitting and run the tubes to the surface of the machine. The mine worker will then pump grease into the tube. However, the mine worker may be next to, on top of, or under the machine. This task is typically performed during regularly scheduled maintenance.
- Changing continuous miner bits. The bits on the cutting head of the continuous miner become worn during the mining process and must be replaced. Continuous miners vary in number of bits per square meter of the drum (cutting head) and may range as much as 0.06–0.08 bits per square meter. This job is performed by one or more persons. The scoop operator delivers the bucket of bits and the mine worker will change only those bits that are dull. The drum of the continuous miner has holes into which the base of the bit slides. The bit is then held in place by a pin. This pin is removed or put in place using pliers. Thus, to remove a dull bit, the mine worker uses a pair of pliers to remove the pin, slides the dull bit out of place, slides the new bit into place, and then uses pliers to insert the pin again. Frequently, these bits get "stuck" and a hammer is needed to remove the pin or bit from the drum and place a new bit in place.
- Moving or advancing belt. Coal is transported out of the mine using belt conveyors. As the mine advances, additional belt will need to be erected. Advancing the belt requires more belt structure to be added (e.g., frames with rollers, structures to which the frame with rollers are attached) to the previously existing belt structure. When more belt structure must be erected, the scoop will deliver these materials to the general area of construction. These materials are then manually transported from the delivery location to the point of construction. Lengthening the belt structure requires the existing belt to be spliced to add an additional piece of belt. Thus, mine workers must also drag, lift, or carry belting material. Due to the heavy nature of the belting material, mines frequently advance belt at pre-determined lengths (e.g., every two cross cuts) and cut the belt for this length. Then, when the mine workers need to pull more on, they have a set location (normally at the head of the section) where the belting was loaded off from a car into a belt loader. The belt is then added and pulled from there. Mine workers will also have racks that they put the belt on, and then load these racks onto a scoop if needed.
- Scooping faces. The mine worker will use the scoop to pick up loose rock and coal and either push it towards the face for the continuous miner to retrieve or transport it to the belt drive hopper where it is dumped into the hopper that leads to the belt.
- Operating the roof bolter. A roof bolter machine is used to reinforce the mine roof by drilling and installing bolts through the roof. The mine worker positions himself next to the roof bolter where he can reach the control levers. Drill steels, bits, bolts, resin, plates, and any other supplemental roof supports (e.g., straps) are typically stored on top of the roof bolter. The mine worker will retrieve these supplies and throw them

forward near the boom arm. The drill steel and bit are mounted on the boom arm and a hole is drilled into the mine roof. Once the hole is complete these components are then removed, resin is pushed into the hole in the mine roof, and the bolt and plate are mounted to the boom arm. The bolt is then spun into the hole containing the resin, torqued, and held until the resin sets. Once the bolts in a given row are installed, the mine worker will move to the back of the machine and use controls to move the roof bolter forward to the location where the next row of bolts will be installed.

- Operating the mobile bridge. The mobile bridge, like the shuttle car (see description for operating the shuttle car below), is one option for an underground haulage vehicle used to transport raw coal from the continuous miner to the belt conveyor. The mine worker is positioned next to, and facing, the machine and its controls. The mine worker will then move the mobile bridge forward or backward while looking to either side to avoid collisions with other equipment, the mine rib, or other mine workers.
- Operating the shuttle car. The shuttle car, like the mobile bridge, is one option for an underground haulage vehicle used to transport coal from the continuous miner to the belt conveyor. The mine worker typically rides in the operator's compartment which is affixed to the side of the machine. Most compartments are designed with two seats, one facing forward and the other backward. The mine worker will drive the shuttle car to the continuous miner where it is loaded with coal. The mine worker then moves to the opposite seat and drives the shuttle car to the belt hopper. As the mine worker operates the shuttle car, the worker constantly inspects the area visually to avoid collisions with other equipment, the mine rib, trailing cables, or other mine workers.
- Operating the continuous miner. The continuous miner is used to rip coal from the face and push this coal to the onboard conveyor. The mine worker is positioned near the machine and uses a large remote control to advance the continuous miner as it cuts coal from the face. The mine worker then uses the conveyor system on the machine to transfer the coal onto the haulage vehicle (e.g., mobile bridge, shuttle car). While operating the machine, the mine worker is constantly observing the cutting drum, the body of the machine, and the haulage vehicle to ensure that they are not in a position where the machinery could cause a striking or pinning accident.
- Moving about the mine. The mine worker will adopt a posture depending upon the current working height, shape and weight of materials/supplies they may be transporting, and the total distance to be traveled.

After identifying the tasks they perform, the mine workers then looked at a schematic of postures (Fig. 1) and selected the two postures they use the most to perform the task. The mine workers were offered the opportunity to describe a posture that did not appear in the schematic if their most commonly used postures were not shown. The mine workers then identified the most physically demanding and the least physically demanding tasks. The researchers verified that the mine workers' self-reported postures compared well with how they actually perform their duties through qualitative observations of the tasks as they were performed in the mine.

3. Results

Of the 64 mine workers involved in the study, 41 indicated a specific task that they felt was the least demanding and 37 indicated a task that they felt was the most demanding. Of the 41 mine workers who reported the least demanding task, 14% identified tramming, 17% identified riding the mantrip in and out of the mine, and 20% identified running the scoop. Of the 37 mine workers who reported a most demanding task, handling the continuous miner cable and shoveling was reported by 24% and 35% of the respondents, respectively.

Table 1 describes the number of workers who reported performing each task, their job classifications, and the primary and secondary postures they used to perform the task.

The primary posture was determined to be the posture that was reported by the largest number of workers and the secondary posture was the posture used by the next largest number of workers.

Many tasks were performed by a variety of job classifications. Of the 18 tasks, 12 (67%) were performed by at least two different job classifications; 6 tasks (33%) were performed by four or more job classifications and included: hanging curtain, advancing the power load center, building stoppings, rock dusting, operating the roof bolter, and shoveling. While advancing the power load center is not a daily task, the other 5 tasks are performed at a high frequency in underground coal mines. Operating the roof bolter typically requires a higher skill level than the other 5 tasks in this group. Of the 18 tasks, 32% had a primary or secondary posture that involved crawling (two-point or four-point crawling). Of these tasks, those that are typically performed on a daily basis include: mechanic duties, hanging cable, moving about the mine, and scooping faces. The other 15 tasks required kneeling near full flexion, kneeling near 90° knee flexion, and kneeling on one knee. Squatting was only reported for operating the continuous miner.

Two unique postures not included in Fig. 1 were identified by the mine workers: sitting on buttocks with lower legs folded towards the body and crossed at the ankle (sitting crossed legged) and sitting back on a seat in a reclined position. The mine workers that reported sitting crossed legged were mobile bridge operators who worked for one particular mine. At this mine, a rubber mat was

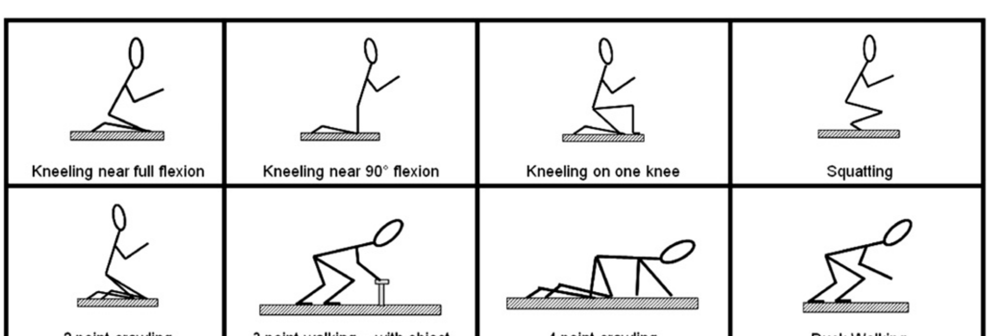


Fig. 1. Schematic of postures to which mine workers referred when describing the postures they most commonly used to perform various mining tasks.

affixed to the side of the mobile bridge near the operator controls. The workers would sit on the mat and be dragged along the mine floor next to the machine. The authors are not aware of any other mine that follows this practice. The workers who reported sitting in a reclined position were shuttle car operators who sit in the operator's compartment affixed to the machine.

Table 2 illustrates the first and second most frequently reported postures by job classification. Interestingly, kneeling near full flexion was the most frequently reported posture for all seven job classifications. The second most frequently reported posture varied across the job classifications. Scoop operators, continuous miner operators, and foremen all indicated the need to frequently crawl. Maintenance shift workers indicated that they duck walk (i.e., stooped walking) routinely. Contrary to this, the roof bolter operators, mechanics, and beltmen indicated that they kneel near 90° of knee flexion on a regular basis.

4. Discussion

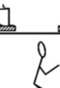
In this study, postures used by low-seam coal mine workers were evaluated based upon job classification and tasks specific to underground coal mining. While a variety of postures were used for the various tasks, mine workers in all job classifications reported kneeling near full flexion to be the most predominant posture used across all tasks they performed at the mine. However, several differences were noted between job classifications when evaluating the second most predominant posture. Interestingly, over one third of the job tasks investigated were performed by at least four different job classifications. The most demanding tasks were handling the continuous miner cable and shoveling as reported by 24% and 35% of the respondents, respectively. The researchers' observations in the field correlated well with the questionnaire data suggesting that the mine workers were able to appropriately identify the postures they used for the various tasks. Based on the postures identified in this study and the findings from other published works, the authors have drawn three main conclusions which will be discussed in more detail.

First, for environments with a restricted vertical height such as low-seam mining, squatting should be avoided. Previous data demonstrated that squatting while performing a lateral lift with a block resulted in the knee extensors exhibiting more than twice the amount of activity as the kneeling postures tested. For example, these muscles exhibited 30% maximum voluntary contraction (MVC) during a squat and only 15% MVC when kneeling near 90° of knee flexion, the most upright posture with the second lowest muscle activity (Gallagher et al., 2011; Moore et al., 2010; NIOSH, 2011). The additional muscle activity required to maintain a squatting posture relative to other postures may lead to an earlier onset of fatigue. Moreover, squatting creates a significant change in internal joint structure orientations which occur in high flexion. Femoral "rollback" causes the lateral compartment of the femur to move 30 mm posterior and the medial compartment to move 9 mm when in a deep squat (Williams and Logan, 2004). This rollback increases the varus moments at the knee when squatting (Pollard et al., 2011). Additionally, in high flexion the meniscus is essential in distributing tibiofemoral compressive force and sustains significant forces (Li et al., 2004; Yao et al., 2008).

Operating the continuous miner was a task associated with frequent squatting (See Table 1). This posture is likely used because it affords great mobility, allowing operators to move quickly to avoid hazards. However, this enhanced mobility comes with a cost of decreased stability, increased meniscal loading, and increased risks for the long term development of osteoarthritis and meniscal injuries (Amin et al., 2008; Baker et al., 2003; Coggon et al., 2000; Pollard and Porter, 2011; Yao et al., 2008). The exposure to the risk factors associated with squatting factors are likely to be high in continuous miner operators as they perform this task for the duration of their shift. Consideration should be given to design tools or strategies to minimize the operators' need or preference to squat for sustained periods.

Second, when performing lateral lifting tasks kneeling near full flexion should be avoided. Kneeling near full flexion was reported as the most frequently used posture by all job classifications (see Table 2). This is likely due to the fact that it requires the least amount of muscle activity to maintain (when compared to other

Table 2
This table shows the most frequently reported and second most frequently reported postures by job classification.

Job Classification	Most frequently reported posture	Second most frequently reported posture
Roof Bolter Operator (n=14)		
Maintenance Shift Worker (n=10)		 
Scoop Operator (n=6)		
Mechanics (n=6)		
Continuous Miner Operator (n=5)		
Foreman (n=5)		 
Beltman (n=2)		

kneeling and squatting postures), creates a large base of support, and has reduced pressures at the knee and internal stresses (Gallagher et al., 2011; Pollard, 2009; Porter et al., 2010; Pollard and Porter, 2011). However, like squatting, kneeling near full flexion results in increased femoral rollback and may increase the stresses applied to the meniscus (Pollard, 2008; Pollard et al., 2011). Additionally, when sitting on the heels, the orientation of the ankle may cause large rotational moments at the knee which could have detrimental effects on the meniscus, ligaments, and cartilage. Therefore, foot posture is an important consideration when kneeling near full flexion. The added effect of a lateral lifting task, while kneeling may increase the twisting at the knee thereby compounding the effects increased varus/valgus and internal/external rotational moments. For these reasons, the combination of lateral lifting while kneeling near full flexion is not ideal. Rather, kneeling near 90° of knee flexion should be the worker's first choice as it requires less muscle activity than the other postures available (kneeling on one knee, squatting) and does not expose the knee to large moments. When kneeling near 90° the upper body is positioned close to the knee, thereby reducing the flexion moment at the knee. Moreover, kneeling near 90° of knee flexion does not expose the knee to the large shear forces, which could be up to 20% body weight, observed when kneeling on one knee (Pollard et al., 2011).

Practical reasons such as the height of the mine may limit a worker's ability to select kneeling near 90° of knee flexion. In this case, kneeling on one knee will become necessary. However, the worker should consciously alternate the knee in contact with the ground to minimize the impact on any one knee. Lateral lifts frequently occur in the underground coal mining environment. This recommendation would impact how workers perform lateral lifts when completing tasks such as: hanging cable, hanging curtain, building stoppings, loading or unloading supplies, shoveling, rock dusting, advancing power load center, and moving or advancing belt.

Third, unlike the lateral lifting scenario discussed above, maintaining a static posture results in knee loading and muscle activity such that the mine worker *should* consider kneeling near full flexion and sitting on their heels. Although kneeling near full flexion is associated with injuries, there are many benefits to this posture that are realized when statically kneeling. It requires minimal muscle activity, it allows the worker to maintain an upright torso in low heights, and it is associated with decreased loading at the knee. Additionally the risk of skin effects is reduced in this postures, as is has a 9.7 psi lower pressure when compared to kneeling on one knee (Porter et al., 2010). It is important to note that prolonged use of kneeling near full flexion without deviation is not recommended. Cartilage is avascular and is nourished by synovial fluid within the joint capsule. Joint motion allows this fluid to flow throughout the joint space providing nutrition (O'Hara et al., 1990). Static kneeling or squatting does not allow cartilage to receive the necessary nutrition. Therefore, when performing static kneeling in any posture, one should frequently rotate between postures, assuming a more upright kneeling posture when possible. Frequent breaks where the knee is flexed and extended through its full range of motion allowing nutrients to the cartilage should also be considered. Furthermore, to reduce the risk of damage to the meniscus, workers should attempt to keep their ankles straight allowing their heels to stay in line with their torso. This will reduce the rotational moments at the knee and increase the force transmitted through the heels, thereby reducing the normal and shear loading at the knee (Pollard et al., 2011; Teichtahl et al., 2006; Lynn et al., 2008). Reducing the loading at the knee is vital in this posture and can be accomplished by increasing the loading through the foot when sitting on the heels or through the use of a body-weight-assist device. A device worn at the ankles or on the boot will provide body weight support by reducing the flexion angle of the knee and supporting some upper body weight (Fig. 2). Static kneeling postures are frequently used in underground coal mining regardless of job type (see Table 2). In fact, the only job tasks that did not list static kneeling near full flexion as a primary or secondary posture were advancing the power load center, hanging cable, scooping faces, and operating the shuttle car (see Table 1).

There are several limitations to this study. First, only four mines were evaluated all of which were located in Pennsylvania. However, the environmental conditions (i.e., wet, dry, undulating mine roof) and the equipment used (i.e., shuttle car, mobile bridge) were different across these mines. Therefore, the findings in this study should be representative of the low-seam mining community. During observation periods, the researchers observed the postures used by the mine workers to perform various tasks which correlated well with what the mine workers had self-reported.

The previously reported biomechanical data demonstrated that the pressure on the knee varied somewhat depending upon the selected posture and the existence of a lateral lift (Mayton et al., 2010; Moore et al., 2009; Porter et al., 2010). However, it is important to note that the magnitude of pressure applied to the knee in all postures is of concern. Therefore, while minimizing the time spent in those detrimental postures is an important component of reducing the risk of knee injuries, it cannot be the only component. Future investigations should consider evaluating the effect of these postures on the entire body (e.g., knee, ankle, back) while subjects simulate the tasks described in this paper. With this information, a postural rotation strategy may be developed for each task that maximizes the overall benefit of each posture for the worker while minimizing any detrimental effects. This information could be incorporated into various ergonomics processes or software programs used by safety and health professionals in the mining industry to disseminate this information (Burgess-Limerick et al., 2007; Torma-Krajewski et al., 2007).

Fig. 2. A body weight support device worn at the ankle that reduces the flexion angle at the knee and increases the distribution of upper body weight through the heels.

5. Conclusion

Low-seam coal mine workers perform numerous tasks throughout their work day. While there are always multiple ways to perform one task, the restricted vertical workspaces and design of commonly used mining equipment severely limit the postures available for these workers. In effect, mine workers are forced to perform work while kneeling and squatting. This study found that low-seam coal mine workers predominantly use the kneeling near full flexion posture to perform work which has been associated with the development of knee osteoarthritis. Given the restricted environment, it is imperative for miners to modify their posture through postural rotation strategies or through the use of protective equipment designed to reduce the loading at their knees. Therefore, NIOSH has partnered with a kneepad manufacturer and industrial designers to develop a novel kneepad and evaluate body weight assist devices that will address the high pressures at the knee and the desire to adopt kneeling near full flexion for many tasks. Evaluation of these products will incorporate biomechanical data and mine worker feedback.

6. Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Acknowledgments

The authors would like to acknowledge Alan Mayton, William Porter, Susan Bealko (formerly of NIOSH), Jeffrey Welsh, and Eric Rainis (formerly of NIOSH) for their assistance in data collection. Rox Coal, Inc. and TJS Mining, Inc. are acknowledged for providing researchers from NIOSH with the opportunity to collect data at their mine sites. The authors would also like to thank Greg Green for providing details regarding how various mining tasks are performed.

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