Comparing estimated low back loads from control interventions for underground coal mine roof bolter operators

Dean H. Ambrose[1] and Gregory P. Cole[2]

ABSTRACT

NIOSH researchers conducted a study to evaluate control interventions that reduce the severity of muscle recruitment and spine loads resulting from roof bolting in different work postures and mine seam heights. Researchers developed databases of predicted forces on the L4/L5 spinal joint and ten trunk muscles by processing captured motions from test subjects using Jack's modeling and simulation software. The databases represent test subjects during a bolting cycle when (1) the materials handled (drill steel, wrench and roof bolt) were on the tray and were their original weights (MO), (2) the materials handled were on the tray and were half their original weights (MH), and (3) the materials handled were relocated in anticipation of reducing the predicted low back stress experienced by an operator (MR). Results of this study indicate that all work postures and seam heights tested benefit from weight reduction of materials handled and benefit *extremely* well in decreased response force from relocating the materials handled. Comparing MO to MH and MR, the percentage of compression and shear force reduction for MH ranges from 0% to -16% and MR ranges from -24% to -73%. Also, the percentage of trunk muscle force reduction for MH ranges from 0% to -42% and MR ranges from -28% to -73%. The mining industry can use this information to reduce loads on the low back through better work postures from redesigning the machine's workstation and modifying bolting cycle work procedures.

INTRODUCTION

Low back disorders continue to be the most costly and common musculoskeletal problem facing society today. Back problems are second only to the common cold as the reason that most people visit physicians. During 1999-2003, the Mine Safety and Health Administration reported 41,406 injuries in underground coal mines and 9,984 of those injuries occurred while operating mobile equipment [MSHA 1999-2003]. From this data, 34% of back injuries sustained from operating mobile mine equipment occurred to operators of roof bolting machines and was second only to back injuries experienced while mine personnel performed maintenance on equipment (35% of back injuries). This may be due to workers in underground coal mines must often work in reduced vertical workspace where standing upright is not possible and work posturing typically includes kneeling either on one or both knees. Experts such as Anderson [1991], Kelsey and White [1980], Liira et al. [1996], Phillips and Repperger [2002], and Pope [1989] generally accept that the risk of suffering from low back disorders is associated with body work postures and during lifting activities at the workplace.

Roof bolts are the principal method of roof support in mines and are essential to ventilation and safety. Roof bolting is one of the most basic functions and a dangerous job in underground coal mining operations. After miner crews remove a section of the coal seam, roof bolting machine operators install bolts (steel rods) to secure areas of unsupported roof. A bolter crew's typical work sequence includes tramming and positioning the machine, general preparation and setup, drilling a hole and installing a bolt. Drilling bolt holes involves inserting the drill steel in the chuck (adding extension steels if necessary), changing the bits, drilling the hole, and removing the steel. Bolt installation involves making up bolt and washer, inserting resins in the hole if necessary, bending bolts, inserting bolts into the hole, aligning the bolts, raising bolts, and spinning to mix resin or torque the installed bolt. The sequence repeats until the assigned area of the roof is secure and then the machine trams to a new location.

The roof bolter operator does his or her job in a confined environment in a limited working height such as 114-cm. This restricted work environment can put the operator in awkward postures for performing or completing his or her tasks. Ambrose [2000, 2001] stated that incident investigation reports from MSHA do not contain scientific information to aid in studying musculoskeletal problems associated with underground mine machine operators. Field experiments with human subjects (machine operators) are also not feasible because of safety and ethical issues to both the investigators and equipment operators. Therefore, this study[3] examines the load effects and compares control interventions on the low back of underground roof bolter operators by posture and seam height using statistical methods on data collected using digital human simulations.

METHOD

SUBJECTS - Since the objective of the study was not to duplicate the entire mining population, but to represent an accurate sample for the roof bolter computer model, a sample size of twelve was chosen. Ten male and two female subjects experienced in roof bolting operation from the United Mine Workers of America volunteered to perform a series of tasks associated with a roof bolting cycle. Table 1 illustrates an excellent spread of test subject's anthropometry showing for each operator their percentile, height, weight, age, and sex. Two female miners were study volunteers that represented the 24th- percentile male operators, because the target population is 99% male. Sample size of the data is an accurate picture of the roof bolter population in that it refers to males ranging from 24th-percentile to 92nd-percentile.

Table 1. – Test subject anthropometry

subject	percentile	height (cm)	weight (kg)	age (yrs)	sex
human 1	84	180.3	84.9	47	M
human 2	51	175.5	61.6	54	M
human 3	61	176.3	80.6	41	M
human 4	58	175.8	81.4	44	M
human 5	79	178.8	84.3	49	M
human 6	92	182.6	88.0	49	M
human 7	24 (male)	168.9	77.0	53	F
human 8	24 (male)	168.7	76.4	47	F
human 9	63	177.0	83.4	50	M
human 10	91	182.4	89.9	47	M
human 11	59	176.0	83.0	44	M
human 12	49	173.5	79.3	48	M

EXPERIMENTAL DESIGN - The study examined spinal joint and trunk muscle loads when the subject performed a roof bolting cycle that included drilling the hole and inserting a roof bolt. All tests were conducted at NIOSH-PRL. Test subject motions were measured and recorded by using Ascensions' MotionStar motion-tracking system and recorded by a computer executing the human motion-capture module in UGS PLM Solution Jack[4] simulation software. Researchers asked test subjects to position themselves in a representative bolt insertion position with respect to a working wooden mock-up of a boom assembly (fig. 1) and perform roof-bolting procedures as they would on the job. Due to the limitations of the MotionStar motion- tracking system around ferrous metals, Bartels et al [2001, 2003] constructed the wooden mock-up from plans provided by J. H. Fletcher & Co.; the boom assembly mock-up was an exact physical reconstruction of the original equipment.

Figure 1. - Operator working the wooden mock-up

The independent test variables consisted of seven posture/seam height combinations. Subjects served as a random effect. In this study, researchers manipulated the following lifting postures: kneeling on the right knee, kneeling on the left knee, kneeling on both knees the left knee, kneeling on both knees (kneeling postures were used in 114-cm, 152-cm seams) and standing (only possible in the 183-cm seam).

Three databases containing force and moment values for the L4/L5 spinal joint and the forces for ten trunk muscles were prepared by processing the captured motions from each subject using Jack software's *Task Analysis Toolkit – Lower Back Analysis*. The databases represent the test subjects performing a bolting cycle when (1) the materials handled (drill steel, wrench and roof bolt) were on the tray and were their original weights (MO), (2) the materials handled were on the tray and were half their original weights (MH), and (3) materials handled were relocated (MR).

Concerning MR, rather than reaching for the material on the tray, the drill hung from the canopy, the wrench was attached to the boom arm, and the bolt was placed beside the operator (fig. 2). Each location was chosen in anticipation of reducing the predicted low back stress experienced by an operator.

The spinal joint load predictions include: lateral shear force (F_X), anterior-posterior *(AP)* shear force (F_Y), compression force (F_Z), forward bending moment (M_X), lateral bending moment (M_Y), twisting moment (M_Z). The trunk muscle force predictions were obtained for lateral moves with the right and left erectors (RES, LES), extending the torso with the right and left latissimus dorsi (RLD, LLD), and support /flex movement with the right and left external obliques (REO, LEO), the right and left internal oblique (RIO, LIO), and the right and left rectus abdominis (RRA, LRA).

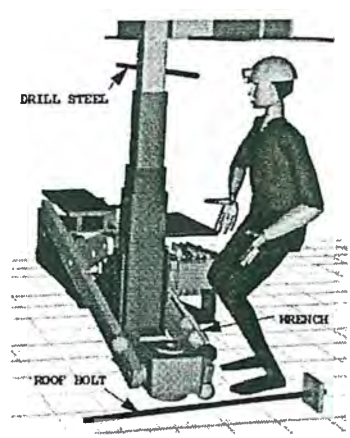

Figure 2. – Relocation: drill hanging from canopy, wrench attached to the boom arm and bolt beside the operator

PROCEDURE AND TASK - Researchers had each subject position themselves in a specified posture with respect to the working boom assembly mock-up. At a given signal, they performed a roof bolting sequence. The specific roof bolting tasks include: insert drill steel, raise boom to drill a hole, lower boom and remove drill steel, put bolt (using a wrench if needed) in chuck, and raise boom to install bolt, torque bolt and lower the boom and remove wrench. For safety reasons, each object (drill, wrench and bolt) held by the test subject was made of wood and weighed no more than one pound. Test subjects repeated the bolting sequence three times in each posture and in each of the seam heights. Researchers recorded each test session using the motion tracking system and a video recorder.

The subject's postures in the 114- and 152-cm seam heights were kneeling on either the left knee, right knee or both knees. The subject's posture in an unrestricted 183-cm seam height would be standing upright if possible or standing hunched over to perform the task.

DATA ANALYSIS – The Jack software bases the *Task Analysis Toolkit* on a biomechanical low back model incorporating anatomical and physiological data from scientific literature, most notably Raschke [1994] and Raschke et al. [1996]. In conjunction with the *toolkit*, a Jack module (TATReporter) outputs the forces generated in the *toolkit* to a formatted spreadsheet file. Moreover, the TATReporter enables researchers to assign weights to the objects that the test subject lifts at specific times during the bolting cycle thus creating realistic loading effects. Video recordings of the test session helped to identify the correct times the test subject held objects. The assigned weights of each object were: drill steel, 2.72 kg; wrench, 1.81 kg; and roof bolt, 3.63 kg.

Researchers obtained three final databases by processing the entire set of spreadsheet files (generated by the *toolkit*) with respect to the compression, shear, and trunk muscle predicted force responses from each test subject. For comparing the intervention controls, researchers used MO, MH, and MR databases to acquire descriptive statistics of force responses by work posture/seam heights. The maximum values from MO descriptive statistics were used as the basis for comparison. The maximum values from MH and MR descriptive statistics were compared to MO to obtain the percentage change in predicted force response. To ascertain severe force responses that should be reduced to prevent injury, the authors used the results from Ambrose et al. [2004, 2005]. That report used predicted maximum values from MO descriptive statistics to perform an analysis of variance (ANOVA) with *a priori* orthogonal contrasts of the following comparisons: standing vs. kneeling, kneeling in 152-cm vs.114-cm seams, kneeling on both knees vs. on one knee, and kneeling on the left knee vs. the right knee. For significant omnibus tests, these contrasts helped elucidate the source of the significant overall F-test. The F statistic determines if the differences among a number of sample means are statistically significant.

RESULTS

MO – MATERIALS WERE THEIR ORIGINAL WEIGHTS

Ambrose et al. [2004, 2005] discusses in detail a study that evaluated the severity of muscle recruitment and spine loads resulting from performance of the roof bolting cycle in different work postures and mine seam heights. The materials handled (drill, wrench and bolt) were their original weights and were located on a tray that was above and slightly behind the boom assembly controls. The following is a brief summary of those findings.

Compression, Shear and Moment Predictions - Notable increases in the compression force (F_Z) and forward bending moments (M_X) were reflected in all cases of seam height or work posture. Compression forces (F_Z) by work posture or seam height exceeded shear forces (F_X and F_Y) by 5 to 39 times, respectfully. Forward moment (M_X) by work posture or seam height exceeded other moments (M_Y and M_Z) by 2 to 8 times, respectfully. Regardless of seam height or work posture, muscle trunk activity in the right or left erectors (RES or LES) accounted for the greater part of muscle activity and experienced 3 to 380 times more force than other muscles.

Source of Variation predictions – Tables 2 and 3 summarize F statistics and contrast for predicting forces and moments acting on the L4/L5 joint and forces on the ten trunk muscles. F-test results (recalculated) compared several variations: standing vs. kneeling, kneeling in 154-cm vs. 114-cm seam heights, both knees posture vs. one knee, and left knee vs. right knee posture.

Table 2. – Summary of F statistics and contrast for predicted forces and moments acting on the L4/L5 joint for MO

Source of variation	F_X	F_Y	F_Z	M_X	M_Y	M_Z
standing vs. kneeling			$F_{6,66} = 6.08^*$ contrast S > K	$F_{6,66} = 18.86^*$ contrast S > K		
kneeling in 152 cm vs. 114 cm		$F_{6,66} = 6.31^*$ contrast 114 > 152	$F_{6,66} = 20.25^*$ contrast 114 > 152	$F_{6,66} = 25.2^*$ contrast 114 > 152		$F_{6,66} = 7.73^*$ contrast 114 > 152
both knees vs. one knee		$F_{6,66} = 4.34^*$ contrast one > both	$F_{6,66} = 6.05^*$ contrast one > both	$F_{6,66} = 6.86^*$ contrast one > both		$F_{6,66} = 3.51^*$ contrast one > both
left knee vs. right knee						$F_{6,66} = 2.73^*$ contrast left > right

* = significant at < 0.05

Legend: F_X = lateral shear force; F_Y = AP shear force; F_Z = compression force; M_X = forward bending moment; M_Y = lateral bending moment; M_Z = twisting moment

Effects of Standing vs. Kneeling - M_X significantly increased and F_Z significantly increased in standing versus kneeling. Neither M_Y, M_Z, F_X or F_Y were affected (p>0.05) when comparing standing to kneeling. RES, LES, LLD, REO, LEO, RIO and LIO showed significant activity in standing versus kneeling with the greatest amount of standing activity in RES, LES and LLD. RLD, RRA and LRA trunk muscles were not affected (p>0.05) when comparing standing posture to kneeling postures.

Effects of Kneeling in 154-cm vs. 114-cm Seam Heights - M_X and M_Z significantly increased in the 114-cm versus 154-cm. F_Z and F_Y significantly increased in the 114-cm versus 154-cm. Neither M_Y nor F_X was affected (p>0.05) by seam heights. RES, LES, RLD, and LLD showed significant activity in 114-cm in versus 154-cm with the greatest amount of 114-cm activity in RES and LES. The REO, LEO, RIO, LIO, RRA and LRA trunk muscles were not affected (p>0.05) when comparing 154-cm to 114-cm seam heights.

Table 3. – Summary of F statistics and contrast for predicted forces on ten trunk muscles for MO

source of variation	RES	LES	RLD	LLD	REO	LEO	RIO	LIO	RRA	LRA
standing vs. kneeling	$F_{6,66} = \mathbf{10.6}^{*}$ contrast S > K	$F_{6,66} = \mathbf{17.64}^{*}$ contrast S > K		$F_{6,66} = \mathbf{13.69}^{*}$ contrast S > K	$F_{6,66} = \mathbf{2.9}^{*}$ contrast S > K	$F_{6,66} = \mathbf{4.82}^{*}$ contrast K > S	$F_{6,66} = \mathbf{3.97}^{*}$ contrast K> S	$F_{6,66} = \mathbf{6.04}^{*}$ contrast S > K		
kneeling in 152 cm vs. 114 cm	$F_{6,66} = \mathbf{31.15}^{*}$ contrast 114 > 152	$F_{6,66} = \mathbf{22.51}^{*}$ contrast 114 > 152	$F_{6,66} = \mathbf{8.68}^{*}$ contrast 114 > 152	$F_{6,66} = \mathbf{8.69}^{*}$ contrast 114 > 152						
both knees vs. one knee	$F_{6,66} = \mathbf{7.77}^{*}$ contrast one > both	$F_{6,66} = \mathbf{7.63}^{*}$ contrast one > both	$F_{6,66} = \mathbf{2.47}^{*}$ contrast one > both	$F_{6,66} = \mathbf{2.99}^{*}$ contrast one > both						
left knee vs. right knee			$F_{6,66} = \mathbf{7.93}^{*}$ contrast left > right	$F_{6,66} = \mathbf{6.95}^{*}$ contrast right > left	$F_{6,66} = \mathbf{5.51}^{*}$ contrast right > left	$F_{6,66} = \mathbf{5.31}^{*}$ contrast left > right	$F_{6,66} = \mathbf{11.20}^{*}$ contrast left > right	$F_{6,66} = \mathbf{9.84}^{*}$ contrast right > left		

*= significant at < 0.05

Legend: lateral moves with the right and left erectors (RES, LES); for extending the torso with the right and left latissimus dorsi (RLD, LLD); and for support /flex movement with the right and left external obliques (REO, LEO), the right and left internal oblique (RIO, LIO), and the right and left rectus abdominis (RRA, LRA)

Effects of Kneeling on Both Knees vs. One-Knee - M_X and M_Z significantly increased in one-knee versus both knees. F_Z and F_Y significantly increased in one-knee versus both knees. RES, LES, RLD, and LLD showed significant activity in the one-knee versus both knees with the greatest amount of one-knee activity in RES and LES. F_X, M_Y and trunk muscles REO, LEO, RIO, LIO, RRA and LRA were not affected ($p>0.05$) when comparing both knees to one-knee.

Effects of the Left Knee vs. the Right Knee - M_Z increased slightly in the left knee versus right knee. Neither M_X, M_Y, F_X, F_Y or F_Z were affected ($p>0.05$) when comparing left knee to right knee. RLD, LEO, and RIO showed significant activity in the left knee versus right knee with the greatest amount of left knee activity in RIO. LLD, REO and LIO showed significant activity in right knee versus left knee with the greatest amount of right knee activity in LIO. RES, LES, RRA and LRA trunk muscles were not affected ($p>0.05$) when comparing left knee to right knee.

MH – MATERIALS WERE ONE-HALF THEIR ORIGINAL WEIGHTS

Table 4 shows the resulting percentage in force response of shears, compression, moments and trunk muscles with the work postures/seam heights between MO and MH.

Work Postures - All work postures benefited from weight reduction of material handled; however, standing posture benefited the least. F_X for both knees benefited 79% better than the right knee and 70% better than the left knee. F_Y for left knee benefited slightly better (1%) than both knees and 75% better than the right knee. F_Y, M_X and M_Y for standing work posture benefited the least and F_X and F_Z did not do much better. M_X for kneeling postures benefited approximately the same. M_Y for left

Table 4. - Resulting percentage in predicted force response of shears, compression, moments and trunk muscles with the work posture and seam height for MH

		work posture				seam height		
		both knees	left knee	right knee	standing	114 cm	152 cm	183 cm
force direction	F_X	-23	-7	-5	-2	-7	-8	-2
	F_Y	-7	-8	-2	0	-16	5	0
	F_Z	-11	-8	-11	-3	-8	-16	-3
	M_X	-8	-9	-9	0	-9	-8	0
	M_Y	-8	-10	-7	0	-10	0	-54
	M_Z	-26	-13	-18	-14	-13	0	88
force on trunk muscles	RES	-13	-10	-11	0	-10	-14	0
	LES	-10	-8	-11	-3	-11	-18	-3
	RLD	-9	-5	-4	-15	-6	0	-15
	LLD	-12	-3	-9	-4	-9	-10	-4
	REO	-2	-13	-10	-12	-10	-8	-12
	LEO	-7	-3	-7	0	-3	0	0
	RIO	-13	-9	-5	0	-9	0	0
	LIO	-7	-13	-2	-1	-2	-9	3
	RRA	-2	0	0	-9	0	-2	-9
	LRA	-2	0	0	-7	0	-2	-7
	LRA	-2	0	0	-7	0	-2	-7

Legend: F_X = lateral shear force; F_Y = AP shear force; F_Z = compression force; M_X = forward bending moment; M_Y = lateral bending moment; M_Z = twisting moment; lateral moves with the right and left erectors (RES, LES); for extending the torso with the right and left latissimus dorsi (RLD, LLD), and for support /flex movement with the right and left external obliques (REO, LEO), the right and left internal oblique (RIO, LIO), and the right and left rectus abdominis (RRA, LRA)

knee benefited 20% better than both knees and 30% better than right knee. RLD for both knees benefited approximately twice that of left or right knee work postures. LIO and REO for the left knee benefited better than both-knee and right knee. RES, RIO and LLD for both-knees benefited better than the left and right knee. Standing work posture benefited much better in RLD, REO, RRA and RLA than other trunk muscles.

Seam Heights - All seam heights benefited from weight reduction of material handled. F_X for 152-cm seam height benefited 13% better than 114-cm and 75% better than 183-cm. F_Y for 114-cm benefited in decrease force response approximately three times better than 152-cm and sixteen times better than 183-cm. F_Z for 152-cm benefited two times better than 114-cm and approximately five times better than 183-cm. M_X for 114-cm and 152-cm benefited approximately the same and eight times better than 183-cm. M_Y and M_Z for 183-cm seam heights benefited much better than 114-cm and 152-cm. RES, LES, LLD and LIO for the 152-cm seam height benefited better than 114-cm and 183-cm. RLD, REO, RRA and LRA trunk muscles for 183-cm benefited much better than 114-cm and 152-cm. LEO and RIO benefited much better for 152-cm and 183-cm.

MR – MATERIALS WERE RELOCATED

Table 5 shows the resulting percentage in force response of shears, compression, moments and trunk muscles with the work postures/seam heights between MO and MR.

Work Postures - All work postures benefited extremely well in decreased force response of shears, compression, moments and trunk muscles from relocating the materials handled. F_X for left knee benefited 6% better than both knees and 24%

Table 5. - Resulting percentage in predicted force response of shears, compression, moments and trunk muscles with the work posture and seam height for MR

		work posture				seam height		
		both knees	left knee	right knee	standing	114 cm	152 cm	183 cm
force direction	F_X	-52	-55	-42	-50	-54	-45	-50
	F_Y	-66	-73	-63	-74	-73	-70	-74
	F_Z	-32	-32	-32	-24	-32	-38	-24
	M_X	-25	-32	-30	-41	-32	-33	-41
	M_Y	-49	-57	-45	-13	-59	-52	-13
	M_Z	-78	-71	-67	-86	-71	-72	-86
force on trunk muscles	RES	-28	-32	-27	-28	-32	-39	-28
	LES	-27	-28	-35	-38	-35	-39	-38
	RLD	-42	-51	-27	-39	-51	-61	-39
	LLD	-35	-30	-48	-44	-44	-45	-44
	REO	-40	-74	-73	-64	-55	-49	-64
	LEO	-51	-51	-25	-4	-51	-39	-4
	RIO	-62	-64	-29	-29	-60	-44	-29
	LIO	-47	-65	-70	-66	-64	-46	-65
	RRA	-99	-92	-92	-83	-92	-99	-83
	LRA	-98	-89	-89	-93	-87	-98	-93
	LRA	-98	-89	-89	-93	-87	-98	-93

Legend: F_X = lateral shear force; F_Y = AP shear force; F_Z = compression force; M_X = forward bending moment; M_Y = lateral bending moment; M_Z = twisting moment; lateral moves with the right and left erectors (RES, LES); for extending the torso with the right and left latissimus dorsi (RLD, LLD), and for support /flex movement with the right and left external obliques (REO, LEO), the right and left internal oblique (RIO, LIO), and the right and left rectus abdominis (RRA, LRA)

better than right knee. F_Y for standing benefited 2% better than left knee and approximately 10% better than right knee and both knee work postures. F_Z shows kneeling work postures were the same in decrease force response and 25% better than standing. M_X shows standing benefited much better than kneeling work postures. M_Y shows left knee benefited much better in decrease force response than both knee and slightly better for standing. M_Z for standing benefited much better than kneeling postures. RES, RLD, REO and RIO for the left knee benefited better in decrease force response than other work postures. For LEO, both knees and left knee benefited better than right knee and standing. LLD and LIO show the right knee benefited better than other work postures. LES for standing benefited better than other work postures. RRA and LRA for both knees reflect the highest decrease force response than any other work postures.

<u>Seam Heights</u> - All seam heights benefited extremely well. F_X for 114-cm seam height benefited 8% better than 183-cm and 17% better than 152-cm. F_Y for 183-cm seam height benefited 6% better than 152-cm and approximately 2% better than 114-cm. F_Z shows 152-cm seam height benefited slightly better in decreased force response than 114-cm and 152-cm. M_X and M_Z for 183-cm seam height benefited much better than 114-cm and 152-cm seam heights. M_Y shows for 114-cm seam height benefited 12% better than 152-cm and 78% better than 183-cm. RES, LES, RLD, LLD, RRA and LRA for the 152-cm seam height benefited better than 114-cm and 183-cm. LEO and RIO for 114-cm seam height benefited better than 152-cm and 183-cm. REO and LID for 183-cm seam height benefited better than 114-cm and 152-cm.

DISCUSSION

The percentage in predicted force response of shears, compression, moments and trunk muscles between MO and MH revealed a benefit for both work postures and seam heights. Unfortunately, no major reduction was found from MH; nevertheless, this should encourage further research into lighter materials. At present, it is doubtful manufacturers could economically produce lighter drill steels, wrenches or roof bolts.

The percentage in the force response of shears, compression, moments and trunk muscles between MO and MR revealed an extreme benefit for both work postures and seam heights. Two relatively inexpensive changes to roof bolter equipment and one procedural change are all that would be needed to benefit from MR: install a rack to hold the steel drill, a mechanism to secure a wrench to the boom arm, and instruct the operators to place the bolt next to them. The roof bolt procedural change could be accepted rather easily, because NIOSH researchers during underground mine visits observed many operators already practicing it.

Results of this research have significant implications in terms of evaluating the risk of low back disorders for underground roof bolter operators who must employ restricted work postures and to improve the design of the jobs they must perform and equipment they operate. Tables 6 and 7 summarize the severe force responses that should be reduced to prevent injury (shaded sections in the tables) and the percentage on predicted force response between MO to MH and MR. Table 6 shows the compression and shear percentage for MH ranges from 0% to -16% and MR ranges from -24% to -73%. Table 7 shows the trunk muscle percentage for MH ranges from 0% to -42% and MR ranges from -28% to -73%.

Table 6. – Summary of percentage in predicted force response of shears, compression, moments acting on the L4/L5 joint for MH and MR

source of variation	Force Directions					
	F_X	F_Y	F_Z	M_X	M_Y	M_Z
standing	-2*	-0	-3	0	0	-14
	-50	-74	-24	-41	-13	-86
kneeling+	-8	-6	-12	-9	-5	-7
	-50	-72	-35	-33	-56	-72
kneeling in 152 cm	-8	+5	-16	-8	0	0
	-45	-70	-38	-33	-52	-72
kneeling in 114 cm	-7	-16	-8	-9	-10	-13
	-54	-73	-32	-32	-59	-71
both knees	-23	-7	-11	-8	-8	-26
	-52	-66	-32	-25	-49	-78
one knee‡	-6	-5	-10	-9	-9	-16
	-49	-68	-32	-31	-60	-69
left knee	-7	-8	-8	-9	-10	-13
	-55	-73	-32	-32	-57	-71
right knee	-5	-2	-11	-9	-7	-18
	-42	-63	-32	-30	-45	-67

* Top percent reflects (MH) when materials handled were on the tray and were half their original weights and the bottom percent reflects (MR) when the materials handled were relocated; Gray shaded areas reflect where improvements are needed as illustrated in Table 2; +Kneeling is the average of the total of kneeling in 152-cm and 114-cm seam heights; ‡One knee is the average of the total of the left knee and right knee

Legend: F_X = lateral shear force; F_Y = AP shear force; F_Z = compression force; M_X = forward bending moment; M_Y = lateral bending moment; M_Z = twisting moment

Because of the results, researchers plan to collaborate with roof bolter manufacturers to implement the control interventions of relocating the drill steel, wrench and roof bolt. Information as to whether operators accept the control intervention can be easily observed after new or refurbished roof bolter machines are placed in service outfitted with modifications that relocate the drill and wrench.

Table 7. – Summary of percentage in predicted force response on ten trunk muscles for MH and MR

source of variation	Trunk muscles									
	RES	LES	RLD	LLD	REO	LEO	RIO	LIO	RRA	LRA
standing	0♦	-3	-15	-4	-42	-0	0	-1	-9	-7
	-28	-38	-39	-41	-64	-4	-29	-66	-83	-93
kneeling+	-12	-15	-3	-10	-9	-2	-5	-6	-1	-1
	-36	-37	-56	-45	-57	-45	-52	-55	-96	-93
kneeling in 152-cm	-14	-18	0	-10	-8	0	0	-9	-2	-2
	-39	-39	-61	-45	-49	-39	-44	-46	-99	-98
kneeling in 114-cm	-10	-11	-6	-9	-10	-3	-9	-2	0	0
	-32	-35	-51	-44	-55	-51	-60	-64	-92	-87
both knees	-13	-10	-9	-12	-2	-7	-13	-7	-2	-2
	-28	-27	-42	-35	-40	-51	-62	-47	-99	-98
one knee‡	-11	-10	-5	-6	-12	-5	-7	-8	0	0
	-30	-32	-39	-39	-74	-38	-47	-68	-92	-89
left knee	-10	-8	-5	-3	-13	-3	-9	-13	0	0
	-32	-28	-51	-30	-74	-51	-64	-65	-92	-89
right knee	-11	-11	-4	-9	-10	-7	-5	-2	0	0
	-27	-35	-27	-48	-73	-25	-29	-70	-92	-89

♦ Top percent reflects (MH) when materials handled were on the tray and were half their original weights and the bottom percent reflects (MR) when the materials handled were relocated; Gray shaded areas reflect where improvements are needed as illustrated in Table 3; +Kneeling is the average of the total of kneeling in 152-cm and 114-cm seam heights; ‡One knee is the average of the total of the left knee and right knee

Legend: lateral moves with the right and left erectors (RES, LES); for extending the torso with the right and left latissimus dorsi (RLD, LLD); and for support /flex movement with the right and left external obliques (REO, LEO), the right and left internal oblique (RIO, LIO), and the right and left rectus abdominis (RRA, LRA)

CONCLUSION

The outcome of this study illustrates the benefits of estimating spinal loads for equipment operators using digital human simulations and associated software modules. Three-dimensional computer simulations provide machine designers and safety analysts with a technique for evaluating human motion in the workplace and control interventions.

Results of this study indicate that all work postures benefit from weight reduction of material handled; however, standing posture or the 183-cm seam height benefited the least. All work postures and mine seam heights benefited extremely well in decreased response force from relocating the material handled. Subsequently, NIOSH plans to work with roof bolter manufacturers to implement and evaluate this control intervention for its acceptance with the mining industry. This information can impact the mining industry by reducing loads on the low back through better work postures from redesigning the machine's workstation and modifying bolting cycle work procedures.

REFERENCES

1. Ambrose DH, Cole GP, Gallagher S [2005]. Estimating low back loads of underground mine roof bolter operators using digital human simulations. SAE 2004 Transactions Journal of Materials & Manufacturing, July 2005, 837-843.
2. Ambrose DH, Cole GP, Gallagher S [2004]. Estimating low back loads of underground mine roof bolter operators using digital human simulations. Oakland University, Rochester, Michigan: June 15-17, 2004; *Proceedings of the 2004 SAE Digital Human Modeling for Design & Engineering*, number 2004-01-2148, p. 6.

3. Ambrose DH [2000]. A simulation approach analyzing random motion events between a machine and its operator. Ann Arbor, MI: *Proceedings of the 2000 SAE Digital Human Modeling for Design & Engineering*, 2000-01-2160, pp 10.
4. Ambrose DH [2001]. Random motion capture model for studying events between a machine and its operator. Seattle WA: *Proceedings of the Society of Computer Simulation International (SCS) Advance Simulation Technologies Conference 2001*, B154, pp 8.
5. Anderson GB. [1991]. The epidemiology of spinal disorders, *The Adult Spine* (New York: Raven Press), 107-146.
6. Bartels JR, Ambrose DH, Wang R [2001]. Verification and validation of roof bolter simulation models for studying events between a machine and its operator. Alexandria VA: *Proceedings of the 2001 SAE Digital Human Modeling for Design & Engineering*, 2001-01-2088, pp 13.
7. Bartels JR, Kwitowski A, Ambrose DH [2003]. Verification of a roof bolter simulation model, Warrendale, PA: *Proceedings of the Society of Automotive Engineering International (SAE) - Digital Human Modeling for Design and Engineering Conference*, 2003-01-2217, 7 p.
8. Kelsey, JL and White AA II. [1980]. Epidemiology and impact on low back pain, *Spine* 5(2), 133-142.
9. Liira JP, Shannon HS, Chambers LW and Haines TA. [1996]. Long-term back problems and physical work exposures in the 1990 Ontario Health Survey., *American Journal of Public Health*, 86, 382-387.
10. MSHA [1999-2003]. Quarterly employment and coal production, accidents/injuries/ illnesses reported to MSHA under 30 CFR Part 50, 1991–2000. Denver, CO: U.S. Department of Labor, Mine Safety and Health Administration, Office of Injury and Employment Information. Date accessed: August 2004. [http://www.msha.gov/STATS/PART50/p50y2k/p50y2k.HTM.
11. Pope MH. [1989]. Risk indicators in low back pain, *Annals of Medicine*, 21, 287-392.
12. Phillips CA and Repperger DW. [2003]. Physiological state model for human ergonomic workload, *Computers in Biology and Medicine* 33, 143-167.
13. Raschke, U. [1994]. Lumbar muscle activity prediction during dynamic sagittal plane lifting conditions: Physiological and biomechanical modeling considerations. PHD dissertation (Biomechanical Engineering), University of Michigan.
14. Raschke U., Martin BJ and Chaffin DB [1996]. Distributed moment histogram: A neurophysiology based method of agonist and antagonist trunk muscle activity prediction. Journal of Biomechanics Vol 29 (12) pp. 15.

---

[1] Dean H. Ambrose – degrees: BSEE, ASET; Safety Engineer and a Principal Investigator for the National Institute for Occupational Safety & Health (NIOSH) at Pittsburgh Research Laboratory's (PRL) Mining Injury Prevention Branch (MIPB) located at 626 Cochrans Mill Road, Pittsburgh, PA 15236; 412.386.6650; DAmbrose@cdc.gov

[2] Gregory P. Cole – degree: BSCE; Computer Engineer and Computational Research Team leader for NIOSH at PRL's MIPB; 412.386.6744; GPCole@cdc.gov

[3] The findings and conclusions in this report are those of the author(s) and do not represent the views of the National Institute for Occupational Safety and Health.

[4] Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Date February 2, 2006

ROUTING AND TRANSMITTAL SLIP

TO: (Name, office symbol, room number, building, Agency/Post)	Initials	Date
1. ROB TUCHMAN, OD		
2.		
3.		
4.		
5.		

	Action		File		Note and Return
	Approval		For Clearance		Per Conversation
	As Requested		For Correction		Prepare Reply
	Circulate		For Your Information		See Me
	Comment		Investigation		Initial
	Coordination		Justify		

RE: PUBLICATION DISTRIBUTION

ATTACHED ARE 2 COPIES OF THE FOLLOWING PUBLICATION:

DATABASE RECORD NO.: Pub #3037

TITLE OF PAPER: "Comparing Estimated Low Back Loads from Control Interventions for Underground Coal Mine Roof Bolter Operators."

PUBLISHED IN: Proceedings of KOMAG, KOMTECH 2005 Conference

AUTHOR(S): DHAmbrose and GPCole

ADMIN CODE: HCC26

8 DIGIT CAN NUMBER: 69270021

REPORTED IN MONTHLY REPORT: YES

FILLED IN PUBL. AVAILABILITY DATE IN PUBL. DATABASE: YES

Nov 14-17 2005
Zakopane
Poland

2002-9449

DO NOT use this form as a **RECORD** of approvals, concurrences, disposals, clearances, and similar actions

FROM: (Name, org. symbol, Agency/Post)	Room No. – Bldg. 03 - 151
Barb Sheppard, CDC, MASO	Phone No. 412-386-6479 Fax No. 412-386-

5041-102

OPTIONAL FORM 41 (Rev. 7-76)
Prescribed by GSA
FPMR (41 CFR) 101-11.206

KOMTECH Sixth Int'l Scientific & Technical Conference

KOMAG - Publication