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Upper Extremity Joint Moment and Force Predictions when using a Joystick Control

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ABSTRACT

This paper discusses the application of digital human models (DHM) to examine computer generated forces necessary to move specific joysticks by using roof bolter virtual operators to predict the forces experienced on the operator's upper extremities. Using DHM and simulations of static movements, investigators analyzed predictions of joint moment and joint force effects on virtual operator's right wrist, elbow and shoulder and compared them to different body dimensions and work postures. This study exemplifies the ease of estimating upper extremity loads on equipment operators using virtual operators and computer models of equipment and work environment. As expected, comparing results of percentage of joint force and moment reduction using the electronic control and of the mechanical control showed that the electronic control had lower joint forces and joint moments over the mechanical control. The average predicted value of the joint moment on the wrist was 1.84 Nm, elbow 7.85 Nm and shoulder 14.55 Nm and of the joint force on the wrist was 5.06 N, elbow 4.56 N, and shoulder 3.67 N. Because the data illustrates low-level forces to move a joystick, inadvertent actuation of the control is addressed. Regardless of the findings, research is still needed on joysticks in real world situations such as an epidemiological assessment of equipment operators in the field before final recommendations and conclusions can be drawn.

INTRODUCTION [1]

Manufacturers make design modifications to their equipment to improve the safety and efficiency of controlling it. Such is the case of a specific manufacturer of underground mining equipment that offers a mechanical or electronic joystick to control an appendage on a machine. Understanding the full impact that a design modification makes requires the analysis of data from laboratory and field experiments. Data collection from laboratory experiments could include data from test subjects operating mockup equipment or data generated from simulations that contain models of digital humans, machines and work environment. Field data collection takes place at the actual workplace such as in underground coal mine with actual equipment, operators and mine environment.

This paper exemplifies how using a DHM application as a research tool could help investigators begin to examine the impact of equipment modifications. The scope of this paper was not to provide conclusive evidence or results of impact and benefits between joystick controls, but to illustrate the application and expected predictions and results from DHM. The authors' opinion is that more data and analyses are needed to fully understand any impact of machine modifications especially in the case presented in this paper. Additional research could include but not be limited to the following: an epidemiological assessment of modified equipment operators in the field and to determine whether or not laboratory findings correlate with what machine operators are experiencing in the field. This paper documents the investigation of the authors to examine computer generated forces necessary to move an electronic and mechanical joystick by using roof bolter virtual operators to predict joint forces and joint moments on the operator's upper extremities. Researchers analyzed a database of simulation predictions of joint forces and joint moments on the right wrist, elbow and shoulder from combinations of work postures and operators with different body dimensions.

Changing from mechanical to an electronic based control has one prime advantage; it makes the device easier to move, by reducing the force and energy necessary for the operator to accomplish repetitive tasks. In this study the electronic control joystick was a seven inch long lever one inch in diameter that is connected remotely to a hydraulic system through electronic circuits and suitable transducers and

[1] 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.

actuators. The mechanical joystick was a two inch diameter knob attached to a twelve inch long lever that is connected directly to the hydraulic system. Both joysticks where mounted on a roof bolter appendage at the same height from the floor (see figure 1). Located on this appendage is a tool that the operator, using the joystick, would select a function to control its rotation and feed (vertical direction).

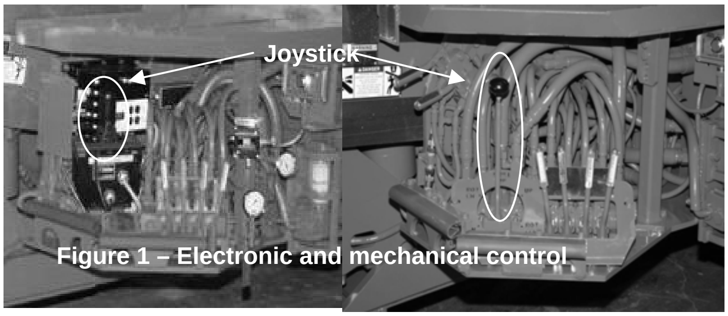


Figure 1 – Electronic and mechanical control

When selecting a function through the joystick, a force on the control must be applied to move a joystick to overcome the spring force used to center the joystick. Once resistive force is overcome, the joystick moves. By continuing to apply a force on the joystick, the joystick is kept in position thus allowing the selected function to continue operation until released. When the joystick is released, a spring-loaded device returns the joystick to neutral position automatically.

Experiments in other industries have used computer models to examine force and moment effects on the wrist, elbow and shoulder. Oliver et al. (2000) used wrist flexion/extension models of Armstrong/Chaffin to determine if joystick controller use in off-road machines could contribute to hand and wrist repetitive strain injuries such as carpal tunnel syndrome (CTS). The investigation revealed that both the external fingertip and predicted internal wrist forces resulting from the use of the joystick were very low; indicating that CTS risk associated with this factor was slight. However, force forward, left/right side motions and all-left side motions were exerted by other portions of the fingers and hand, thereby under-predicting the tendon tension, internal wrist forces and the wrist angles. These observed forces were highest for motions that moved the joysticks to the sides rather than front to back. Consequently, the right and left motions for both hands posed a higher risk for CTS concerns.

Lindbeck et al. (1997) studied the net load and the force distribution in the shoulder during sanding of a ceiling. A biomechanical model predicted the load pattern in the shoulder from measured external forces and body postures. The study showed the proposed method can be used to evaluate loads and force distribution in the shoulder. Moreover, observable individual variations in work technique may explain why some workers develop musculoskeletal disorder while others do not.

Other experiments to determine forces on upper extremities include Niemeyer et al. (2004) and Van Drongelen et al.(2005) examining wheelchair-propulsion efforts on the shoulder and Shimada et al. (2001) on the wrists; Safran et al. (2005) studying sports activities that impart a stress on the elbow; and Hatfield (2003) using a combination of computer tomography, new reverse-engineering software, CAD/CAM solid tools, and computer animations to study the human wrist

METHOD

SUBJECT

Three virtual male subjects, representing different body dimensions having measurements that populate 5^{th}-, 50^{th}-, and 95^{th}-percentile, performed motions associated with joystick that controls a roof bolter boom arm. Table 1 provides information on height and weight of the virtual subjects.

Table 1. – Virtual test subject anthropometric data

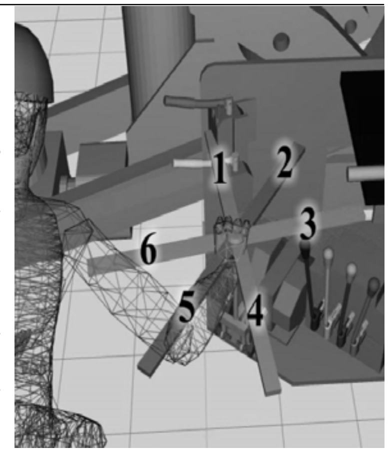
subject	height - cm (in)	weight – kg (lbs)
operator-05	164.6 (64.8)	67.1 (135.8)
operator-50	175.5 (69.1)	84.6 (171.3)
operator-95	186.9 (73.6)	106.8 (216.2)

EXPERIMENTAL DESIGN

The use of virtual human models to analyze workplace hazards and improve workplace design is becoming more prevalent among human factors and ergonomics professionals (Badler et al., 2002; Chaffin, 2002; Ferguson and Marras, 2005). These virtual human models can be driven by human motion analysis techniques, providing the means by which human-machine interactions can be analyzed. Investigators used UGS-PLM Corporation's Jack virtual model and simulation software and its *Loads and Weights* module to generate and collect data on each virtual operator. During data collection, the virtual operator mimicked the operator's right hand controlling the machine functions through a joystick control mechanism. Researchers evaluated a database of predictions of joint moment and force effects on the right wrist, elbow and shoulder. Joint moment predictions include the total force of moment that consists of three individual torques (x, y, x) about the joint axis. Joint force predictions include the total force that is comprised of compression and shear forces. Researchers used only total moment and force values rather then their components, because of the level of the planned investigation. Also, for comparison purposes researchers post-processed the data to calculate percentage of force reduction between joystick controls. Further analysis used mechanical control's resultant forces of joint moment and force predictions on each operator percentile and work posture and their combinations to compare the significance of the force reductions on each body joint.

Table 2 – Relationship of the joystick test direction and function

Direction number and description	Function			
	Rotation	**R**everse **R**otation	**F**eed **Up**	**F**eed **D**ow**n**
1 – Push to the left 45°	R			
2 – Push straight forward	R		FUp	
3 – Push to the right 45°			FUp	
4 – Pull to the right 45°		RR		
5 – Pull straight backward		RR		FDn
6 – Pull to the left 45°				FDn



Researchers tested virtual subjects in a representative work posture with respect to the boom assembly model and posed the right hand on the joystick as the operator would on the job. The independent variables consisted of three virtual subjects in three work postures. Two work postures represented an underground coal mine seam height requiring kneeling and the third represented working in a standing posture for higher seams. In these tests, researchers manipulated work postures and the six different pull and push directions required to move the joystick, see Table 2. For ease of identifying joystick direction, numbers were assigned for each test direction. Also, Fletcher (roof bolter manufacturer) measured in all directions the force to move the actual joysticks. The electronic joystick force averaged 15.6 N (3.5 lbf) and 66.7 N (15 lbf) for the mechanical joystick. These measurements were used to simulate the operator's forces exerted on the joystick.

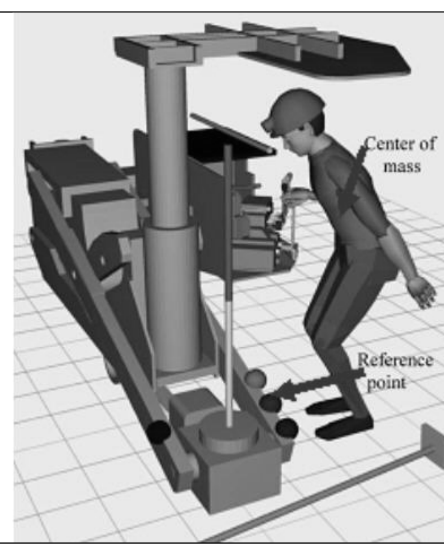
TEST PROCEDURE

Researchers placed each virtual operator in a specified posture with respect to the boom assembly within the virtual computer environment as illustrated in Table 3. Specific distances for each work posture were maintained between the boom arm and operator to accommodate the work space needed for each operator to mimic the pose for operating the joystick. The distance was measured from two reference points, one on the boom arm and the other the virtual operator's center-of-mass site. Table 3 lists the distance from the boom arm for each subject and work posture combination and, shows the two reference points. Ambrose et al. (2005) validated the same reference points and postures used in a previous study regarding roof bolter operators. The distances and postures are within the range to perform bolting tasks. The distances and postures varied slightly as using a joystick limits placement for potential right arm motion and back posturing, so allowing each virtual operator to handle the joystick naturally.

A joystick represents a rigid object that moves perpendicular about a fixed point in six different directions according to Table 2. These directions also helped to locate the force direction at the palm center by aligning the exerted force with both the joystick lever and perpendicular to the joystick top. The study by Oliver et al. (2000) suggests forces on joysticks are exerted by various portions of the hand (fingers and palm); therefore, this study used the palm center of the hand holding the joystick as the start point for load and direction. So for both exerted force values, researchers

Table 3. – Distance (cm – (in)) between boom arm and virtual operator

Virtual operator-(percentile)	Work posture		
	Both knees	Right knee	Standing
Operator-05	66.8 (26.3)	74.2 (29.2)	78.2 (30.8)
Operator-50	70.1 (27.6)	74.2 (29.2)	83.1 (32.7)
Operator-95	73.9 (29.1)	76.7 (30.2)	89.9 (35.4)



collected joint moments and joint forces of the wrist, elbow and shoulder from all six test directions for each operator percentile/work posture combination. Also, operator percentile/work posture combination tests were carried out only once since static data was collected. Static tests started from direction 1 (push-to-the-left-45°) and to simulate other push or pull directions, continued clockwise to test directions 2, 3, 4, 5 and finally 6.

Test Limitations

Jack's *Loads and Weights* module does not have dynamic testing capability. If the module had this capability, tests would have mimicked operator motions in actual working conditions. These include varying test directions to reflect joystick functions typical of a bolting cycle and incorporating the joystick displacement from the neutral position before proceeding on to the next test direction. In addition, dynamic testing would give the ability to generate data on the full-range of hand motions over time prevalent to each joystick control type. Thus, the authors believe that dynamic testing would be more representative of tests conducted in laboratory and field conditions.

DATA ANALYSIS

Jack software bases the *Loads and Weights* module on a biomechanical model incorporating anatomical and physiological data from scientific literature, most notably from research of Grooso et al. [1987, 1988], Raschke [1994, 1996] and Chaffin [1997, 2000]. The module enabled investigators to specify how large a load is, place the load anywhere on the body, and adjust the direction it acts (load vector).

Researchers generated from Jack software a database of predictions with respect to the joint moment and joint force required to move a joystick. The results reflected the joint moment and joint force on the right wrist, elbow and shoulder for combinations of three operator percentiles (5^{th} –, 50^{th} – or 95^{th} –percentile) and work postures (standing, kneeling on both knees and the right knee). Researchers post-processed the database and developed Tables 4, 5 and 6 showing percentage of joint moment and joint force reduction for the electronic control and the resultant joint moment and joint force of the mechanical control.

RESULTS

Data in Tables 4, 5 and 6 shows the predicted range of percentage of reduction using the electronic control and the resultant when using the mechanical control. Percent reduction and resultant range for the joint moment on the wrist was 52.8% (0.3 Nm) to 92.7% (1.1 Nm), elbow 45.7% (8.2 Nm) to 93.3% (10.1 Nm), and shoulder 46.5% (20.4 Nm) to 84.9% (19.1 Nm). Percent reduction and resultant range for the joint force on the wrist was 75.3% (6.8 N) to 76.2% (6.85 N), elbow 63.1% (7 N) to 68.6% (7.2 N), and shoulder 39.6% (7.8 N) to 52.5% (8.1 N). The average predicted reduction of joint moments and joint forces on the wrist were 1.84 Nm and 5.06 N, elbow 7.85 Nm and 4.56 N, and shoulder 14.55 Nm and 3.67 N, respectfully. Further examination used mechanical control's resultant forces of joint moment and force predictions on each operator percentile and work posture and their combinations to compare the significance of the force reductions on each body joint.

Joint Moment Predictions – Results showed the right knee work posture with the highest reduction average of 2.02 Nm for the wrist, 8.3 Nm for the elbow in the both knee posture and 15.4 Nm for the shoulder in the standing posture. Also, the results showed that the 95^{th}-percentitle operator with the highest reduction average for the wrist (2.12 Nm), elbow (8.59 Nm) and shoulder (16.34 Nm). No one combination of work posture and operator percentile showed the highest reduction average for all three joints except standing work posture – 95^{th}-percentile operator showed two with the highest reduction average: 8.59 Nm for the elbow and 16.34 Nm for the shoulder. The combination standing work posture – 5^{th}-percentile operator showed the lowest reduction average for wrist (1.61 Nm), elbow (6.74 Nm) and shoulder (12.94 Nm).

Joint Force Predictions – Results showed the both knee work posture with the highest reduction average for the wrist (5.17 N), elbow (4.78 N) and shoulder (4.23 N) and standing work posture with the lowest reduction average for the wrist (4.85 N), elbow (4.25 N) and shoulder (3.08 N). Joint force data shows the 95^{th}-percentile operator with the highest reduction average for the wrist (5.15 N), elbow (4.66 N) and shoulder (3.96 N) and the 50^{th}-percentile operator with the lowest reduction average for the wrist (4.87 N), elbow (4.43 N) and the 5^{th}-percentile operator's shoulder (3.5 N). No one combination of work posture and operator percentile showed the highest reduction for the wrist, elbow and shoulder.

DISCUSSION

For operating a joystick on an underground roof-bolting machine, results showed that electronic control has a range of lower joint force and joint moment over the mechanical control. The 95^{th}-percentitle operator and both knee work posture shows the greatest reduction in both joint moment and joint force. Because the results were very small values, the joint force variability with the change on joystick test direction was minimal. The average predicted joint moments (1.84 Nm) and joint forces (5.06 N) on the wrist were quite low (with a maximum resistive force of 66.7 N). In comparison, the joint force closely agrees with the average prediction results 6 N (with a maximum resistive force of 80 N) by Oliver's et al. (2000) joystick study. No other joystick studies could be found to date to compare wrist joint moments, elbow and shoulder predictions. This could pose difficulty for future research in validating results on joystick controls using predictions from DHM.

The data generated from simulations took three weeks to collect. This short time span illustrates how quickly data can be generated using DHM. As expected, the data showed low joint moments and joint force predictions. Kong et al. (2006) suggest models estimating low joint forces combined with minimal wrist dynamics are not a major factor in work-related musculoskeletal disorder. No such conclusion can be derived from the relative low joint force predictions using DHM in our study; however, the data did reveal lower joint moment and joint forces when operating an electronic joystick compared to a mechanical joystick control. Despite the findings the authors suggest additional research is needed in real world situations such as an epidemiological assessment of equipment operators in the field that have used both joystick controls. For example, even with electronically controlled joystick's physiological benefits, it doesn't provide as much feedback as those mechanically controlled. Some operators may prefer or even need, the "feel" of the mechanical joystick feedback to safely and efficiently handle the machine. Additional research that emphasizes psychosocial factors will also answer the questions do mine workers prefer or experience less comfort of one joystick over the other and have they found it to be less taxing by the end of their shift. Furthermore, additional predictions from simulations using dynamic tests on realistic virtual operators controlling with their right and left hand can be used to help overcome shortcomings in the outcomes of this initial study. This can be realized if (1) the *Loads and Weigh module* would be expanded to include dynamic testing and (2) testing used realistic anthropometry of virtual test subjects of experience mine workers such as those used by Ambrose et al. (2005).

Because small forces are evident to move the joystick electronic or mechanical controls, this drew attention to the authors regarding concerns of inadvertent actuation of the control. Consequently, Fletcher has addressed this potential problem by designing an electronic control joystick with an "enable" button molded in the knob that is easily depressed with no change of grip. The joystick still moves but no machine functions happen unless the button is depressed.

The mechanical joystick control spring force is higher to keep the spool in the hydraulic control valve centered. Fletcher is investigating lowering this centering spring force but several problems must be overcome. The first is inadvertent actuation. Fletcher has developed an electrical button built into the mechanical joystick head to provide the enable button. Moving the joystick would not make a machine function happen unless the enable button was depressed. The second potential problem resulting from reduction in the hydraulic valve spring centering force is the possible loss of functionality in the valve. The valve design will have to change to overcome this problem.

CONCLUSION

This study illustrates the use of digital human models and simulations for estimating loads for equipment operators. This study showed, in the case of one specific manufacturer, that smaller joint moments and joint forces are apparent to operate an electronic control over a mechanical control. However, smaller actuating forces may result in inadvertent actuation of the control. A solution to this potential problem is an "enable" button deigned into the joystick knob that, when depressed, allows functionality. In this study the average predicted reduction of joint moment on the wrist was 1.84 Nm, elbow 7.85 Nm and shoulder 14.55 Nm and joint force on the wrist was 5.06 N, elbow 4.56 N, and shoulder 3.67 N. This information along with suggested future studies regarding epidemiological assessment of bolter operators in the field and additional dynamic tests on more realistic virtual operators could have an impact on the use of joystick controls. It is cautioned that additional laboratory and field studies are required before final recommendations and conclusions can be made. Note: The findings and conclusions in this report are those of the authors and do not represent the views of the National Institute for Occupational Safety and Health.

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Table 4 –Percentage of joint moment and force reduction using the electronic control and resultant of the mechanical control comparing both knees work posture and operator percentile versus joystick direction and body joint

		Operator percentile for both knees											
		05				50				95			
Joystick direction	Body joint	Joint moment		Joint force		Joint moment		Joint force		Joint moment		Joint force	
		%	Nm	%	N	%	Nm	%	N	%	Nm	%	N
1	wrist	74.3	2.0	76.1	6.8	77.0	1.7	76.1	6.8	72.4	1.7	76.1	6.8
	elbow	73.2	17.2	68.2	7.0	68.0	13.7	68.3	7.1	71.6	17.3	68.3	7.1
	shoulder	68.7	34.1	52.5	7.6	64.9	28.1	52.5	8.0	68.6	27.2	52.5	8.4
2	wrist	71.6	1.3	76.1	6.8	77.0	1.8	76.1	6.8	68.4	2.0	75.5	6.8
	elbow	55.0	6.4	68.4	7.0	50.5	6.9	68.4	7.1	45.7	8.2	63.4	7.1
	shoulder	58.5	24.9	52.5	7.5	52.9	21.6	52.5	7.9	61.0	16.7	51.6	10.3
3	wrist	76.0	3.7	76.1	6.8	76.1	4.1	76.2	6.8	75.4	4.3	76.0	6.8
	elbow	69.4	12.3	68.4	7.0	71.7	18.2	68.5	7.1	71.0	14.9	68.2	7.1
	shoulder	47.8	19.8	52.5	7.5	46.5	20.4	52.5	7.9	54.1	21.7	52.5	8.3
4	wrist	75.2	1.9	76.1	6.8	70.5	2.2	76.2	6.9	67.6	1.9	76.2	6.8
	elbow	74.7	16.6	68.4	7.0	69.5	12.7	68.6	7.2	68.9	18.4	68.5	7.1
	shoulder	67.8	34.7	52.5	7.5	61.9	30.6	52.5	8.2	65.8	28.9	52.5	8.3
5	wrist	73.0	1.1	76.1	6.8	72.2	1.3	75.8	6.8	69.0	2.1	76.2	6.8
	elbow	65.3	4.4	68.4	7.0	54.7	2.2	66.2	7.1	46.0	8.3	68.5	7.1
	shoulder	63.2	21.1	52.5	7.5	55.8	20.6	46.7	7.9	60.3	16.1	52.5	8.3
6	wrist	76.0	3.7	76.1	6.8	75.9	3.9	75.9	6.8	75.5	4.3	75.5	6.8
	elbow	69.3	12.3	68.3	7.1	72.7	15.5	66.2	7.0	71.2	14.9	63.4	7.1
	shoulder	47.9	19.9	52.5	7.9	47.1	18.1	46.6	7.8	54.0	21.5	51.6	10.3

Table 5 –Percentage of joint moment and force reduction using the electronic control and resultant of the mechanical control comparing right knee work posture and operator percentile versus joystick direction and body joint

Joystick direction	Body joint	Operator percentile for right knee											
		05				50				95			
		Joint moment		Joint force		Joint moment		Joint force		Joint moment		Joint force	
		%	Nm	%	N	%	Nm	%	N	%	Nm	%	N
1	wrist	78.3	2.5	75.7	6.8	73.6	2.3	75.9	6.8	74.4	2.6	75.9	6.8
	elbow	74.5	16.6	66.0	7.0	63.1	11.5	66.2	7.0	61.2	12.0	66.2	7.1
	shoulder	77.8	20.3	46.8	7.5	69.3	24.0	46.7	7.9	84.9	19.1	46.7	8.3
2	wrist	82.9	1.5	75.8	6.8	67.8	1.3	75.9	6.8	91.2	3.9	75.9	6.8
	elbow	49.3	3.1	66.2	7.0	63.5	11.6	66.3	7.0	79.2	11.0	66.3	7.1
	shoulder	74.2	15.8	46.8	7.5	58.4	21.2	46.7	7.8	78.2	20.8	46.7	8.3
3	wrist	76.9	3.5	75.8	6.8	75.7	3.8	75.9	6.8	75.2	3.9	75.9	6.8
	elbow	73.8	12.0	66.0	6.9	73.1	21.0	66.2	7.0	71.3	10.6	66.3	7.1
	shoulder	71.9	17.0	46.8	7.5	57.2	24.4	46.7	7.9	69.1	23.3	46.7	8.4
4	wrist	73.6	2.6	75.4	6.8	74.7	2.2	75.8	6.8	71.9	2.6	75.9	6.8
	elbow	73.2	16.7	65.5	6.9	72.0	8.4	66.1	7.1	62.5	10.2	66.3	7.2
	shoulder	74.4	21.3	47.1	7.4	63.7	27.7	46.8	7.9	66.1	24.9	46.7	8.4
5	wrist	69.7	1.7	75.5	6.8	69.9	1.2	75.7	6.8	58.1	1.2	75.9	6.8
	elbow	46.7	4.9	65.6	6.9	71.4	8.9	66.0	7.1	52.0	7.3	66.3	7.2
	shoulder	76.8	15.5	47.0	7.4	60.1	16.9	46.8	8.0	66.9	21.0	46.7	8.4
6	wrist	75.5	3.6	75.8	6.8	75.9	3.8	75.8	6.8	74.9	3.9	75.8	6.8
	elbow	70.1	12.7	66.2	7.0	74.5	20.4	66.2	7.0	72.3	11.0	66.2	7.1
	shoulder	80.7	15.3	46.7	7.5	70.3	13.6	46.7	7.9	74.7	20.8	46.7	8.3

Table 6 –Percentage of joint moment and force reduction using the electronic control and resultant of the mechanical control comparing standing work posture and operator percentile versus joystick direction and body joint

Joystick direction	Body joint	Operator percentile for standing											
		05				50				95			
		Joint moment		Joint force		Joint moment		Joint force		Joint moment		Joint force	
		%	Nm	%	N	%	Nm	%	N	%	Nm	%	N
1	wrist	75.6	2.4	75.4	6.8	75.0	3.5	75.5	6.8	72.1	3.4	75.4	6.8
	elbow	74.1	8.1	63.2	7.0	73.1	12.8	63.4	7.0	70.1	15.1	63.3	7.1
	shoulder	75.9	16.5	40.1	7.5	79.2	23.2	39.8	7.9	74.6	27.9	39.9	8.3
2	wrist	52.8	0.3	75.5	6.8	58.2	0.6	0.9	6.8	61.5	1.8	75.5	6.8
	elbow	64.6	5.6	63.4	7.0	63.7	8.7	11.6	7.0	62.7	15.5	63.4	7.1
	shoulder	70.5	15.6	39.9	7.6	72.3	22.2	24.6	7.8	65.7	30.5	39.9	8.3
3	wrist	75.2	2.0	75.4	6.8	74.0	2.7	75.4	6.8	73.3	3.7	75.5	6.8
	elbow	64.9	5.8	63.3	7.0	62.3	11.0	63.2	7.0	67.9	12.2	63.4	7.1
	shoulder	59.5	10.6	40.0	7.6	62.6	22.6	40.1	7.8	58.4	31.4	39.9	8.3
4	wrist	76.1	2.4	75.4	6.8	76.0	3.5	75.3	6.8	77.3	3.1	75.5	6.8
	elbow	74.7	8.0	63.3	7.0	74.4	12.3	63.2	7.0	76.7	12.8	63.5	7.1
	shoulder	65.8	17.6	40.0	7.5	64.5	31.0	40.2	7.8	61.9	38.5	39.8	8.3
5	wrist	54.9	0.2	75.4	6.8	66.2	0.6	75.3	6.8	92.7	1.1	75.5	6.8
	elbow	68.8	5.4	63.3	6.9	72.6	9.1	63.1	7.0	93.3	10.1	63.5	7.1
	shoulder	67.1	16.1	40.0	7.5	66.0	28.2	40.3	7.8	63.7	32.7	39.8	8.2
6	wrist	75.8	2.0	75.5	6.8	75.6	2.7	75.5	6.8	76.5	3.5	75.6	6.8
	elbow	68.4	5.3	63.6	7.0	72.1	8.2	63.4	7.0	79.1	14.1	63.5	7.1
	shoulder	65.1	10.9	40.3	7.5	67.4	18.9	39.9	7.9	67.6	21.9	39.7	8.2