TRI-PLANAR TRUNK MOTION IN NORTHERN ONTARIO SKIDDER OPERATORS

Jack R.J.[1,2], *Oliver M.*[1,2], *Cation S.*[1] *and Dony R.*[1]

[1]School of Engineering, University of Guelph, Guelph (Ontario), N1G 2W1, Canada
[2]Biophysics Interdepartmental Group, University of Guelph, Guelph (Ontario), N1G 2W1, Canada
rjack@uoguelph.ca

ABSTRACT

This study was conducted to obtain quantitative postural data for skidder operators in three planes of trunk motion under field operating conditions. With 31.0±15.8 minutes of the continuously collected data from seven forestry skidders, it was found that the operators typically sat with a forward facing and slightly extended trunk accompanied by a large lateral bend to the left while driving. When observing the operators picking up and dropping off a load, the operators would adopt a large lateral bend to the left, extend the trunk and rotate the trunk to the right. A flexed trunk, deep lateral bending, and frequent movement between two postures were associated with musculoskeletal health complaints in the skidder operators. Furthermore, visibility requirements and cab design were reported to influence operator postures.

Keywords: posture, trunk, skidder, operator, visibility, cab design, musculoskeletal injury

RÉSUMÉ

Cette étude a été entreprise pour obtenir des données quantitatives résultant de tests posturaux sur des opérateurs de treuil dans l’industrie forestière dans des conditions de fonctionnement en chantier. Basé sur 31.0±15.8 minutes de données enregistrées en continu sur sept treuils, on a constaté que les opérateurs étaient typiquement assis vers l’avant avec le tronc légèrement en extension, accompagné d'une grande courbure latérale vers le gauche pendant qu’ils conduisaient. Quand les opérateurs remplissaient et vidaient la charge du camion, ils adoptaient une grande courbure latérale vers la gauche, une extension du tronc, et une rotation du tronc vers la droite. Un tronc fléchi, un recourbement latéral profond, et un mouvement fréquent entre deux postures étaient associés avec des plaintes de santé de nature musculosquelettiques parmi les opérateurs de treuil. De plus, les conditions de visibilité et la conception de cabine ont aussi influencé la posture des opérateurs.

Mots clés: posture, tronc, treuil, opérateur, visibilité, conception de cabine, blessure musculosquelettique

1. INTRODUCTION

In the forest industry, injuries and/or pain to the arm, neck, shoulder, legs, and lower back are common in mobile machine operators (MMOs) [1-6]. Hagen et al. (1998) [2] found a high prevalence of low back disorders (22.7%) and neck/shoulder disorders (34.8%) in forestry MMOs. Rehn et al. (2002) [5] found that the prevalence of musculoskeletal symptoms of the neck, shoulder, upper back and lower back in forestry MMOs was 61%, 56%, 20% and 47% respectively. The musculoskeletal complaints of these forestry MMOs likely result from a combination of whole-body vibration (WBV) exposure, static driving postures, and repetitive movements associated with the operation of hand and foot controls [1,2,4,6-8].

Seat design, control locations, vision requirements, and the sitting habits of the operator will all influence the postures adopted by forestry MMOs as they bend and twist to view driving routes and attachments, as well as to reach controls [9-16]. Holding these seated postures for extended periods of time has been associated with musculoskeletal problems of the neck, back, shoulders, legs and buttocks [8-11,17-21]. Forestry MMOs also conduct repeated arm movements [3,13] and are exposed to harmful levels of whole-body vibration (WBV) [22-28] while adopting these postures, both of which have been associated with neck and shoulder pain in MMOs [2,3,5,7,8,20,29-31]. WBV has also been positively related to back disorders and low-back pain (LBP) [5,8,18,29-38]. Moreover, WBV has increased harmful effects when combined with adverse postures [20,33].

Although reports linking posture to the incidence of back and neck pain in MMOs are insightful, the current authors have found those reports to be typically qualitative in nature. The lack of quantitative postural data is largely due to the instrumentation difficulties associated with field studies in which operators perform their job tasks under real operating conditions. As a result, it is known that forestry MMOs adopt twisted and/or bent postures [13,28], but one cannot accurately state the magnitudes or timing of these postures. The goal of this paper is to provide quantitative data for three planes of trunk motion (lateral bending, forward flexion/extension and axial twisting) under field operating conditions for Northern Ontario skidder operators. In addition, connections between the measured postures and self-reported musculoskeletal symptoms for the trunk, neck and shoulder will be explored, along with cab design and job task features that influenced the operator's posture.

2. METHODS

2.1 Tri-planar Trunk Motion Measurements

Three planes of trunk motion (flexion/extension in the sagittal plane, lateral trunk bending in the coronal plane, and axial trunk twisting) were monitored for seven male Northern Ontario skidder operators under field operating conditions (refer to Table 1 for a summary of operator characteristics). A biaxial goniometer (Biometrics Ltd. SG150, Gwent, UK) mounted over the axis of rotation of the left hip was used to determine the trunk flexion/extension and lateral trunk bending (LTB) angles relative to the thigh (Figure 1). A torsiometer (Biometrics Ltd. Q110, Gwent, UK) mounted over the lumbar spine was used to determine the axial trunk twisting (TWST) angles (Figure 1). Here the angle measured represents the rotation of the lower thoracic spine (approximately T9-T12) relative to the sacrum. Upon mounting of the goniometer and torsiometer, the skidder operators entered the machine cabs and adopted an upright seated posture (i.e. a vertical trunk position, with no LTB or TWST) used to represent a 0° flexion/extension, 0° LTB, and 0° TWST posture. While adopting this upright seated posture, all goniometer and torsiometer raw voltage outputs were set to zero, as suggested by Jack and Oliver (2006) [39]. This "on subject zeroing" was performed to remove any bias errors that may occur from misalignment during the mounting of the goniometer and torsiometer, as well as any biases that may have resulted from tissue displacements during the adoption of the seated posture inside the skidder cab. After the goniometer and torsiometer bias removal, flexion was then defined as any forward movement of the trunk from the initial upright posture (represented by a positive angle) used for "on subject zeroing", and extension was any backward trunk motion from this initial posture (represented by a negative angle) (Figure 1). For both LTB and TWST, 0 degrees indicated an upright posture with the subject facing straight ahead, a negative angle indicated a TWST or LTB to the left, and a positive angle indicated a TWST or LTB to the right (Figure 1).

Table 1: Summary of operator characteristics and driving experience

	Operator							Mean	Standard Deviation
	1	2	3	4	5	6	7		
Age (years)	39	32	33	28	50	50	56	41.14	10.84
Weight (kg)	145.15	61.23	86.18	83.91	102.06	72.57	97.52	92.66	27.01
Height (m)	1.80	1.73	1.91	1.78	1.73	1.75	1.80	1.79	0.06
Years operating mobile equipment	20.00	11.00	13.00	5.00	33.00	15.00	35.00	18.86	11.29
Years operating a skidder	20.00	5.00	13.00	0.08	33.00	12.00	35.00	16.87	13.29
Average hours/day operating a skidder	11.00	11.00	8.00	14.00	14.00	3.00	8.00	9.86	3.89

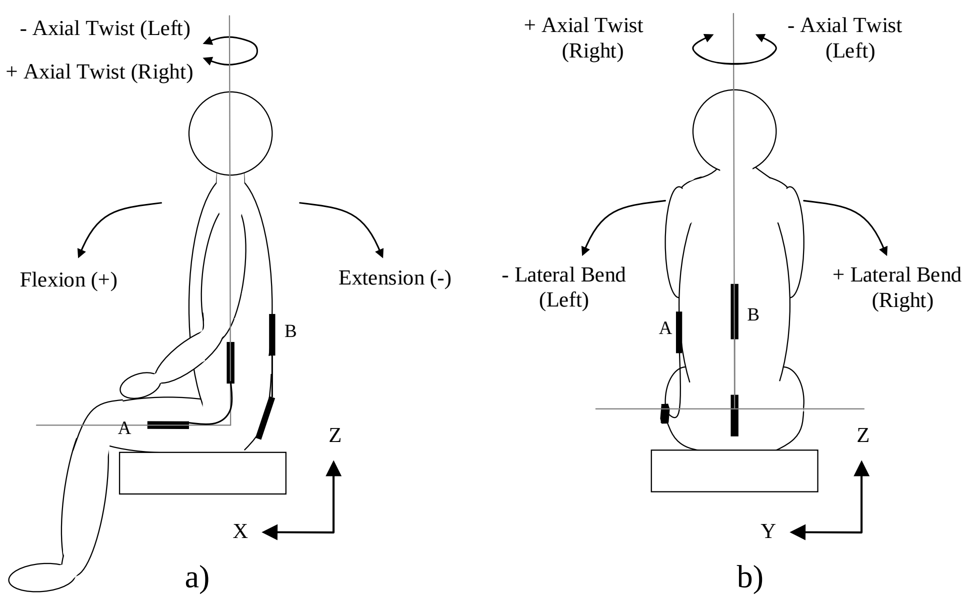

Figure 1: a) Left Sagittal view of the goniometer and torsiometer mounting placements. b) Posterior view of the goniometer and torsiometer mounting placements. Note: A indicates the goniometer used to measure trunk flexion/extension and lateral trunk bending, and B indicates the torsiometer used to measure axial trunk twisting.

Raw goniometer and torsiometer voltages were collected with a SOMAT™ 2100 Field Computer (nCode, Urbana, Illinois, USA) at a rate of 500Hz while all seven skidder operators preformed their normal operating duties. Five operating conditions were observed and monitored; driving with a load (DL), driving without a load (DUL), picking up a load (PUAL), dropping off a load (DOAL), and ploughing logs (refer to Table 2 for a full break down of the task operating times). A digital video camera (Sony DCR-PC 109, Shinagawa, Tokyo, Japan) mounted in the skidder cab was used to determine when the skidder operator was performing each of the aforementioned tasks. The video data in conjunction with an audible beep and simultaneous voltage spike recorded by a Biometrics Ltd. P98 data logger (Gwent, UK) was used to time stamp the data. The Biometrics Ltd. data logger and SOMAT™ 2100 Field Computer time histories were then aligned using a multiple resolution cross correlation procedure described in Jack et al. (2007) [40]. The goniometer and torsiometer data were then divided into the various skidder operating conditions for analysis.

2.1.1 Data Analysis

The raw goniometer and torsiometer voltages collected with the SOMAT™ 2100 Field Computer were 4th order zero-lag Butterworth low-pass filtered with at a cut-off frequency of 40Hz. The filtered voltages were then converted to trunk angles by applying experimentally determined calibration equations (refer to section 2.1.2). The trunk angle data were then processed with a wavelet de-noising program (refer to section 2.1.3) to remove the majority of vibration induced motion from the data time histories while allowing as much voluntary motion as possible to remain. The wavelet de-noised trunk angle time histories were then used to determine the percentage of operating time that the skidder operators adopted a given posture. A series of 5° bins were created (i.e. -5° to 0°, 0° to 5°, etc.) and the percentage of time that the operator flexed/extended their trunk, LTB and TWST within that range of angles was determined for each trial of each operating condition. The data were then averaged for each operating condition and across all operating conditions. All data post processing was completed using custom MATLAB™ 7.0.4 (MathWorks Inc., Natick, Massachusetts, USA) programs.

2.1.2 Goniometer Calibration

Calibration data were collected with the SOMAT™ 2100 Field Computer. A four point calibration was conducted for trunk flexion/extension, and a five point calibration was conducted for LTB. The biaxial goniometer used to monitor both flexion/extension and LTB was calibrated in a position that reflected the position that it would be in while mounted on the skidder operators in the field. Trunk flexion/extension was calibrated with 0° of LTB, and LTB was calibrated with the goniometer flexed to 90° of flexion. A five point calibration was conducted for TWST. In all instances, three seconds of data were collected for each calibration point with a sample rate of 500Hz. Three goniometer and torsiometer calibrations were conducted, one prior to field data collection, one mid way through the data collection period (i.e. after half of the skidders had been tested), and one upon the completion of field data collection. The average of the three calibration slopes was applied to the data (refer to Table 3 for calibration results).

2.1.3 Wavelet De-noising

The human body resonates in the X and Y axes at approximately 1-7Hz [41-44] and the dominate translational and rotational WBV exposure frequencies from the skidders driven here were between 1-2 Hz [23]. Therefore, much of the operator trunk motion monitored could be the result of vibration. The goal of this paper is to determine the underlying voluntary motions and postures required by the operators to perform their skidder operating duties. As a result, a wavelet de-noising procedure was preformed.

Table 2: Average and total data collection times for the five operating conditions monitored during field data collection.

		Operator							Total Operating Time (min)
		1	2	3	4	5	6	7	
Driving With a Load	n	3	2	6	10	6	6	4	
	Average Trial Time (min)	1.85	0.83	1.75	0.98	3.50	5.22	4.07	
	Standard Deviation (min)	0.43	0.71	1.33	0.20	1.57	2.97	2.23	
	Total Operating Time (min)	5.55	1.67	10.50	9.78	21.00	31.30	16.28	96.08
Driving Without a Load	n	4	3	5	11	6	6	3	
	Average Trial Time (min)	3.00	1.22	3.29	0.96	3.49	3.37	4.54	
	Standard Deviation (min)	1.05	0.94	1.64	0.29	1.56	3.58	2.94	
	Total Operating Time (min)	11.98	3.65	16.43	10.57	20.93	20.23	13.62	97.41
Dropping Off A Load	n	3	2	3	8	5	-	4	
	Average Trial Time (min)	0.38	0.12	0.11	0.15	0.27	-	0.18	
	Standard Deviation (min)	0.53	0.12	0.06	0.10	0.31	-	0.07	
	Total Operating Time (min)	1.13	0.23	0.33	1.22	1.35	-	0.72	4.98
Picking Up A Load	n	3	2	6	9	5	1	3	
	Average Trial Time (min)	0.41	0.41	0.54	0.24	0.67	-	0.18	
	Standard Deviation (min)	0.09	0.25	0.66	0.15	0.20	-	0.06	
	Total Operating Time (min)	1.22	0.82	3.23	2.12	3.33	0.42	0.55	11.69
Ploughing	n	-	-	1	6	-	1	-	
	Average Trial Time (min)	-	-	-	0.66	-	-	-	
	Standard Deviation (min)	-	-	-	0.27	-	-	-	
	Total Operating Time (min)	-	-	1.17	3.97	-	1.85	-	6.99
Total Operating Time (min)		19.88	6.36	31.66	27.65	46.62	53.80	31.17	217.14

Table 3: Goniometer and torsiometer calibration information.

Goniometer/ Torsiometer	Sensitivity (°/V)			Bias			r^2-values Are All Greater Than†
Trunk Flexion	1134.33	±	34.30	67.37	±	10.60	0.997
Lateral Trunk Bend	2420.97	±	222.74	-50.71	±	25.54	0.989
Trunk Twist	-630.21	±	42.98	-4.13	±	28.78	0.999

†Values represent the minimum r^2-value from all calibration equations determined.

The wavelet de-noising entailed and initial 3rd order Daubechies 15 level wavelet decomposition. Once the signal was decomposed, ten, 10s data windows were used to obtain noise estimates for each wavelet decomposition level, at a time when the operator was believed to be adopting a static posture. After the noise estimation, frequency components above 10 Hz were removed because voluntary human movement signals are typically below 10Hz [45]. All wavelet decomposition levels with 0.1Hz or less were left completely in tack, as vibration exposures from the skidders driven in this study were typically above 0.1Hz [23]. Were there was overlap between the vibration and potential voluntary human signals, the noise estimates were used to remove the vibration induced signal from the underlying voluntary human movement signal. The removal of the vibration signal was accomplished by setting a “soft” threshold to 3-standard deviations about the mean of the noise estimate amplitudes for each of the N wavelet resolutions between approximately 0.1 Hz and 10 Hz (levels E through J). This resulted in the removal of 99.7% of the potential vibration signal determined from the noise estimate and leaves only the potential human movement signals with amplitudes above the threshold limit. Once the wavelet coefficients had been thresholded, the modified coefficients were used to reconstruct the de-noised signal.

2.2 Visibility, Cab Design and Musculoskeletal Health Surveys

A survey was administered to the skidder operators prior to field data collection. The operators were asked to provide information regarding aspects of their skidder cab design and their job requirements that affected their posture. In addition, the skidder operators were also asked about their musculoskeletal injury history for each of the nine body regions outlined in Table 4. Refer to Table 4, Table 5, and Table 6 for the questions asked during the survey.

3. RESULTS

3.1 Posture Analysis

The skidder operators observed in this study were typically seated with a forward facing and slightly extended trunk as they use the backrest for support while DL and DUL (Figure 2 and Figure 3). The operators’ spent 89% and 78% of there time between 15° of TWST to the right and left while DL and DUL respectively. While DL and DUL, operators were found to adopt an extended trunk posture 80% and 78% of the time. It was also observed that the operators adopted a prominent LTB to the left during the DL and DUL conditions (Figure 2 and Figure 3). This observation is likely the result of operators using their arm and the armrest to support the trunk. The aforementioned results reflect pooled averages of the posture data across all seven of the skidder operators observed. It should be noted however, that some operators adopted postures that were notably different from the overall average. Operator 4 adopted a more prominent trunk extension while Operator 6 spent much of his time flexing the trunk as they drove with and without a load. A tendency to TWST to the right (Operators 3 and 5) or left (Operator 7), while DL and DUL was also observed in some operators. In addition, the trend towards a large LTB to the left was consistent among all skidder operators, with the exception of Operator 4 and 6 while DL, and Operator 5 when DUL.

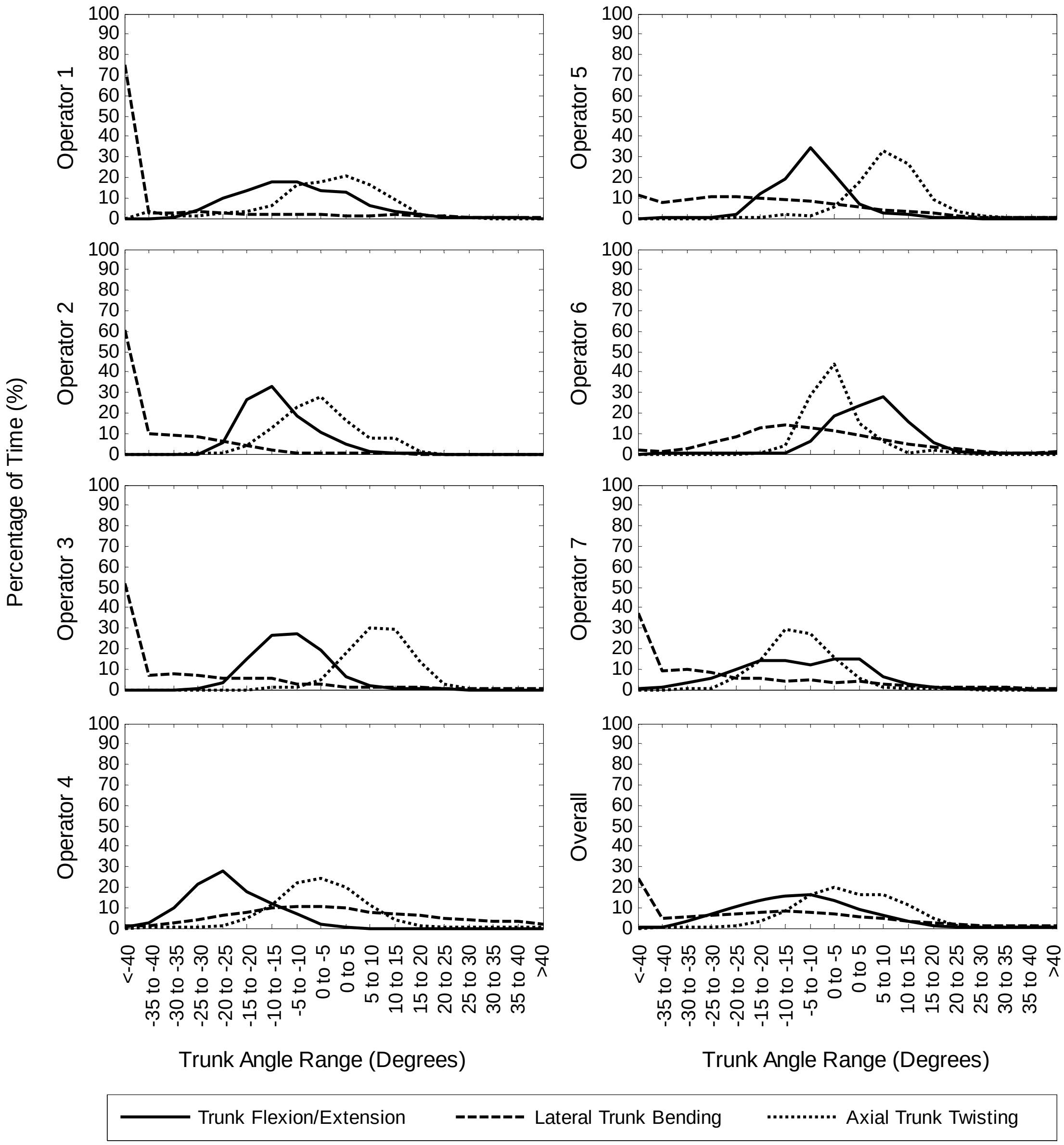

Figure 2: Average percentage of time spent flexing/extending, lateral bending, and axially twisted while driving with a load (DL). Results represent the average of all DL trials collected for each skidder operator, and the overall average of the DL condition for all seven operators.

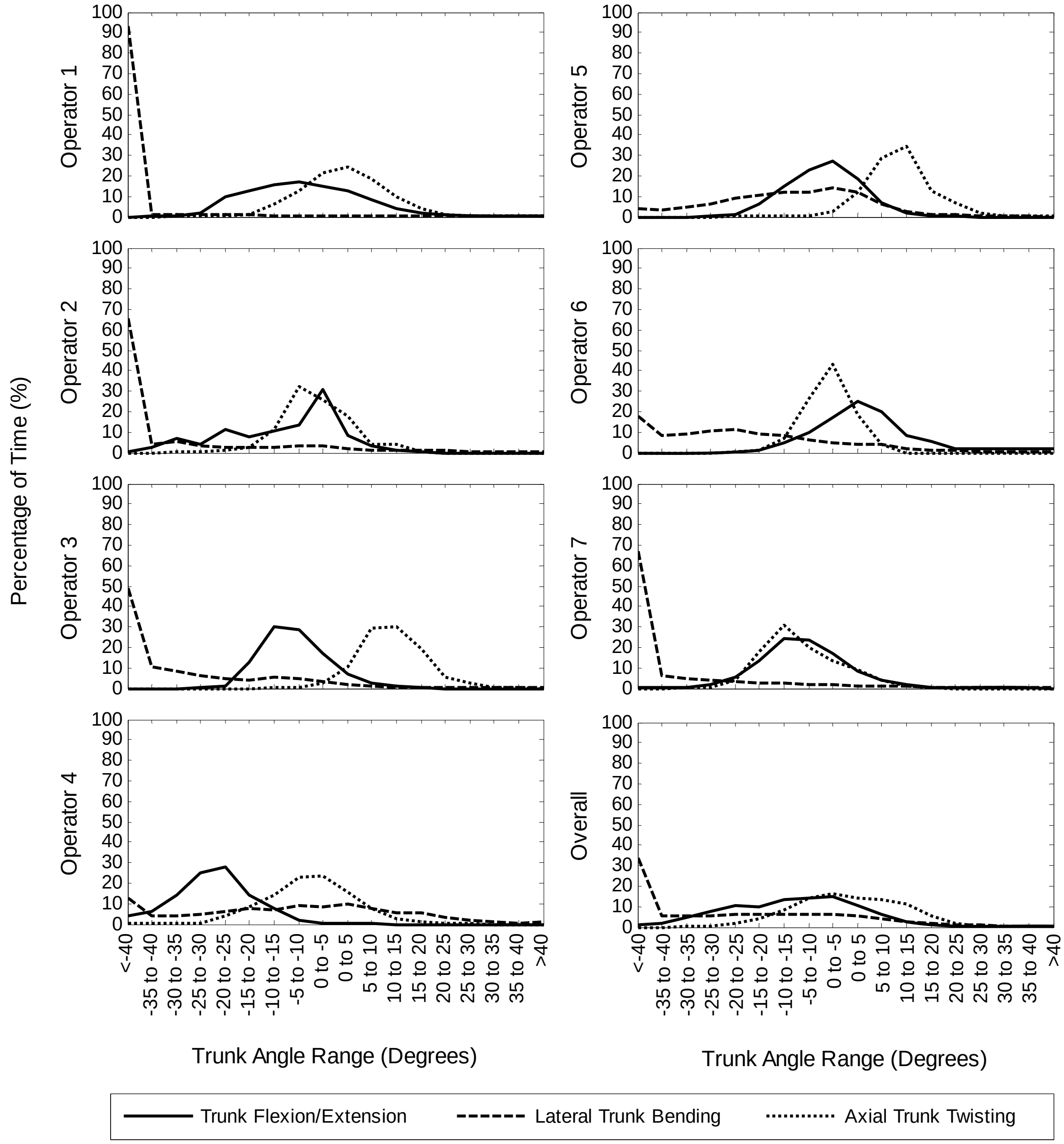

Figure 3: Average percentage of time spent flexing/extending, lateral bending, and axially twisted while driving without a load (DUL). Results represent the average of all DUL trials collected for each skidder operator, and the overall average of the DUL condition for all seven operators.

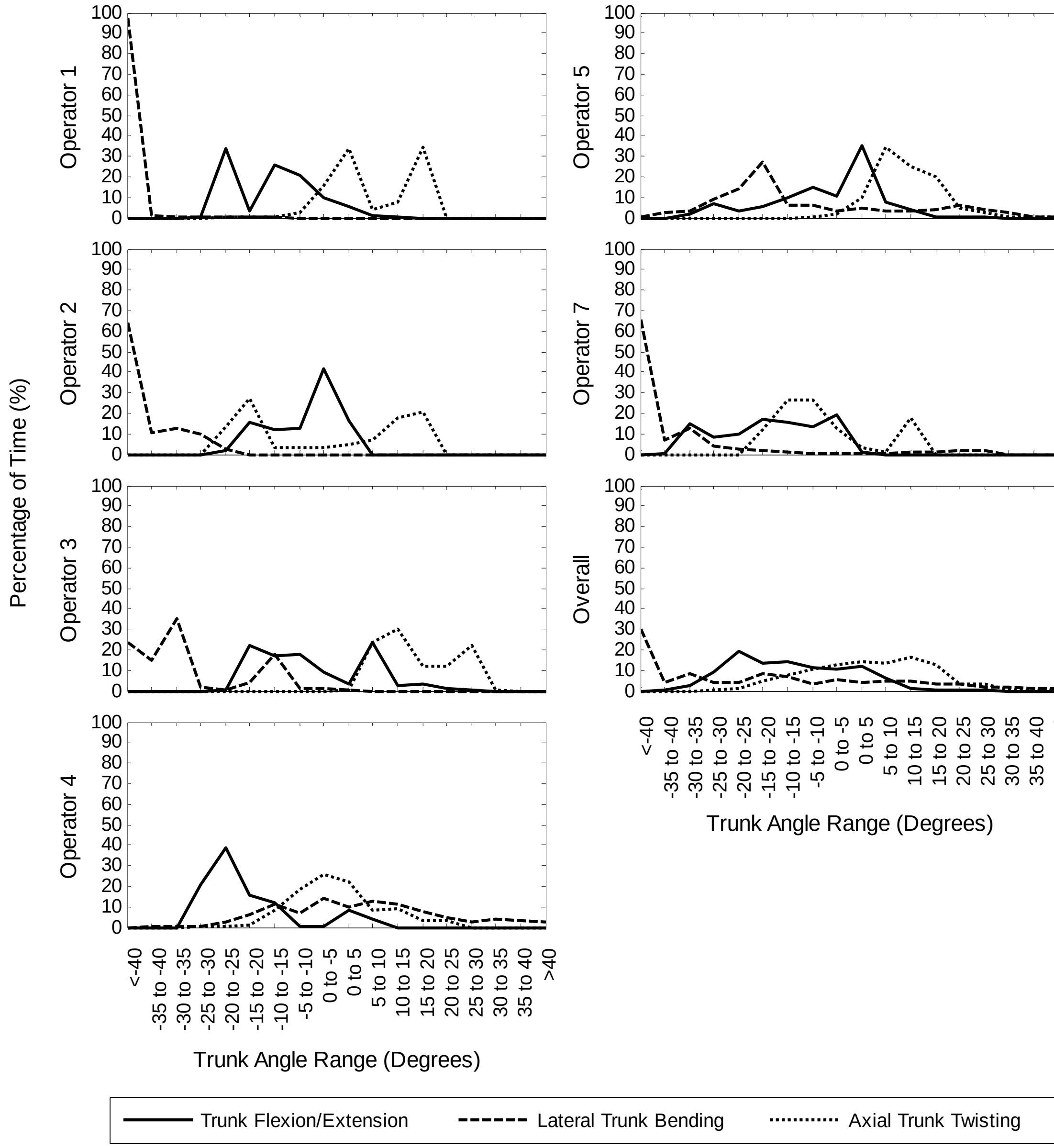

Figure 4: Average percentage of time spent flexing/extending, lateral bending, and axially twisted while dropping off a load (DOAL). Results represent the average of all DOAL trials collected for each skidder operator, and the overall average of the DOAL condition for all seven operators.

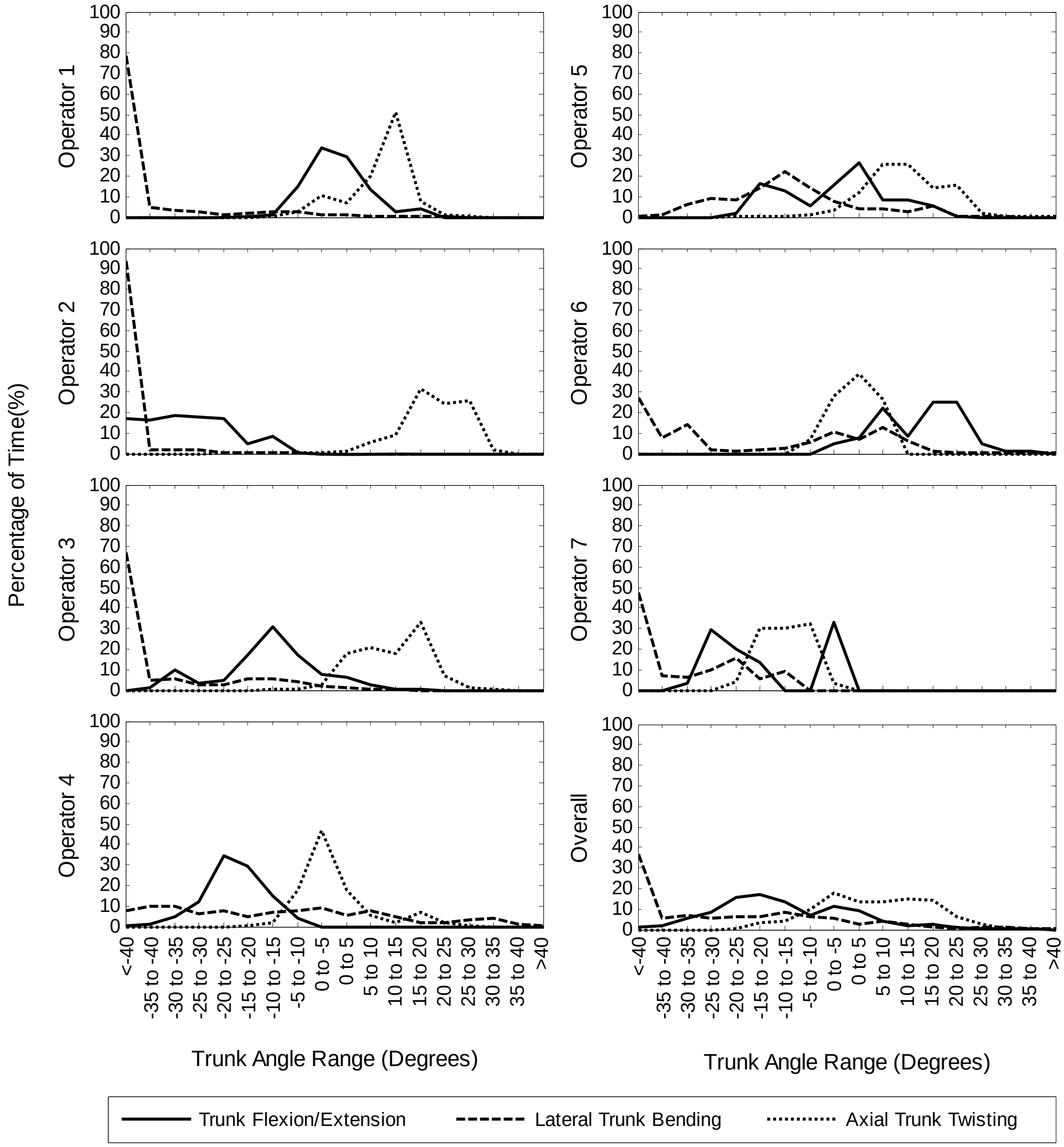

Figure 5: Average percentage of time spent flexing/extending, lateral bending, and axially twisted while picking up a load (PUAL). Results represent the average of all PUAL trials collected for each skidder operator, and the overall average of the PUAL condition for all seven operators.

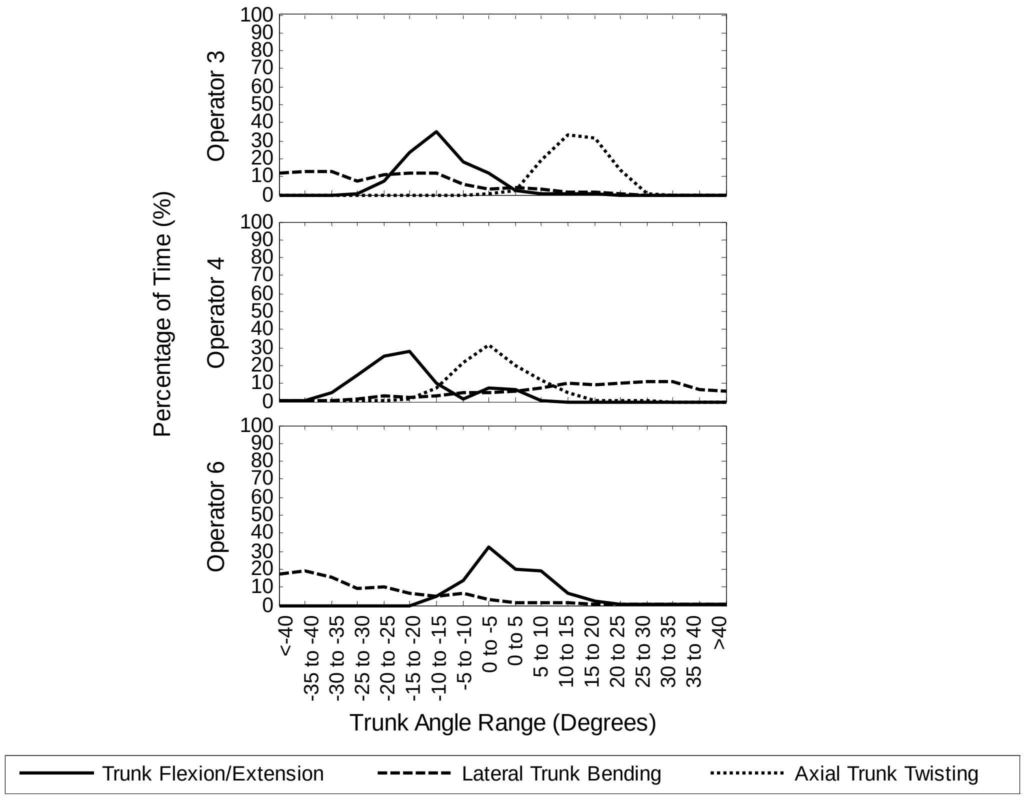

Figure 6: Average percentage of time spent flexing/extending, lateral bending, and axially twisted while ploughing. Results represent the average of all ploughing trials collected for each skidder operator (Note: n=6 for Operator 4, and n=1 for Operators 3 and 6).

When observing the operators PUAL and DOAL, it was found that the operators would adopt a large LTB, extend the trunk (greater than what was observed while driving), and TWST to the right (Figure 4 and Figure 5). On average, the skidder operators spent 46% of their time extending between 10° and 25° while PUAL and DOAL. These operators also TWST to the right (between 0° and 20° of axial trunk twisting) 69% of the time while DOAL, and 74% of the time while PUAL. This posture is consistent with one which would be required to view the load. Again, it is worth noting that individual operator differences do exist. Operator 5 and 6 spent a large percentage of time PUAL with a flexed trunk, and Operators 3 and 5 both flex and extend their trunk for a large percentage of time while DOAL. It was noted though, that Operator 3 reduced the amount of time spent adopting a flexed trunk considerably, and Operator 5 spent more time adopting greater angles of trunk flexion and extension when PUAL. In addition, several operators displayed some distinct patterns of trunk extension, spending much of their time within two or three ranges of extension while DOAL (Operator 1 and 2) or PUAL (Operator 2 and 7). In contrast, Operator 6 spent the majority of time PUAL between two distinct ranges of trunk flexion. With regards to TWST, it was found that Operators 1, 3 and 5 would TWST to the right while DOAL and PUAL, and Operator 7 would TWST to the left. Operator 1 did however; spend a small amount of time TWST to the left while PUAL, just as Operator 7 also spent a fair amount of time TWST to the right while DOAL. When DOAL, Operator 1 spent the majority of his time TWST to the right within two distinct angle ranges. Also, Operator 2 and 4 were found to adopt both right and left TWST postures while DOAL, but Operator 2 only TWST to the right while PUAL. As with DL and DUL, the LTB observed in the operators demonstrated the same trend towards a large LTB to the left while DOAL and PUAL. Similar to the driving conditions, Operator 4 spent a great amount of time (38%) laterally bending <20° to the left while DOAL, and even laterally bent to the right (59% of the time). Operator 4 did increase the amount of time he spent LTB to the left while PUAL though. It was also noted that, in contrast to the driving conditions, Operator 5, 6 and 7 adopted LTB postures within more distinct ranges of motion while PUAL and DOAL.

In addition to the above tasks, three skidder operators preformed a ploughing task, in which the front blade is used to push and pile logs. Since two of the three skidder operators only preformed the ploughing task once, pooled averages of the data for the three operators were not calculated, as the results would be skewed to reflect the actions of the third operator who preformed 6 ploughing trials. The postures adopted by each operator individually are reported in Figure 6. It was found that the skidder operators adopted an extended trunk, and predominantly bent and twisted to one side.

3.2 Health Survey

Table 4 provides a summary of the musculoskeletal health survey results. With the exception of Operator 7 while DL and Operator 2 while DUL, the operators with the greatest percentage of time extending the trunk >20° while DL and DUL were the ones who reported musculoskeletal symptoms for the neck (Operators 1, 4 and 6). In addition the operators who spent the most amount of time with a trunk flexed >10° while DL and DUL (Operators 1 and 6) reported the most severe musculoskeletal symptoms for the neck. The operator who reported upper back symptoms (Operator 6) was the operator who spent the greatest percentage of his driving time (DL and DUL), and time PUAL and ploughing a load with a flexed trunk. Finally, one operator reported LBP (Operator 1), and was found to spend the most time adopting a deep LTB to the left while DL, DUL, DOAL and PUAL. It was also noted that the operator who reported LBP spent the majority of time while DOAL within two distinct flexion/extension and TWST postures indicating frequent movement between these two postures as the operator attempted to view the load.

3.3 Visibility and Posture

When asked “When operating a skidder, are there any times when you have to adjust your posture in order see what you are doing or where you are going?”, all seven skidder operators answered “yes”. Table 5 provides a summary of the visibility and posture survey conducted. From the survey, the requirement to view the rear of the vehicle and the carried load was the most commonly reported reason for the operators to alter their posture, as the seat location lead to a combination of TWST, LTB and flexion or extension of the trunk to improve the operator’s view. The operator’s ability to observe the terrain while driving was another factor commonly reported to affect posture, in particular, trunk and neck rotation.

3.4 Cab Design and Posture

Two of the seven skidder operators surveyed indicated that they had to adjust their posture in order manipulate machine controls. Table 6 provides a summary of the cab design and posture survey conducted. In both cases, the operators stated that the location of the hand controls required them to rotate their trunk and neck, in order to perform the task at hand.

Table 4: Summary of findings from a musculoskeletal health survey.

Body region	Question Asked				
	Have you experienced any ache, pain, numbness or discomfort?	When was the last episode of ache, pain, numbness or discomfort?	How would you rate the severity of the last episode of ache, pain, numbness or discomfort?	What task or activity do you think brought on the last episode?	Do you have any suggestions to avoid future episodes of ache, pain, numbness or discomfort?
	Operators who responded "Yes" †	Operator Response††	Operator Response†††	Operator Response	Operator Response
Neck	1	1-2 weeks ago	2	Twisting to look at the rear of the skidder	Improve seat the placement
	4	Today	1	Twisting to look at the rear of the skidder	Increase the seat rotation angle
	6	Today	2	WBV and shock exposure	Improved seating (air-ride seats)
					Reduce driving speed
					Use the arms and steering wheel to help stabilize the body while driving
Shoulder	-	-	-	-	-
Upper Back	6	Within the last week	2	Muscle fatigue while driving	Improved seating (air-ride seats)
					Reduce driving speed
Elbows	-	-	-	-	-
Low Back	1	1-6 months ago	3	WBV and Shock exposure	Better quality seating
Wrists/ Hands	3	Today	2	Hand-arm vibration Exposure (steering wheel)	-
Hips/ Thighs/ Buttocks	4	Today	1	Sitting	Change seat/seat cushion
Knees	5	Today	2	Stabilizing the body while driving.	-
Ankles/ Feet	5	Today	2	Stabilizing the body while driving.	-

†Only musculoskeletal complaints attributed to the operation of a skidder are reported.
††Operators were asked to indicate if you have had an ache, pain, numbness or discomfort in the area in the last year, month, week, or day.
††† Operators were asked to rate the severity of the last episode of ache, pain, numbness or discomfort with the following scale. 1 = mild, 2 = moderate, 3 = severe, 4 = very, very severe

Table 5: Summary of findings from a visibility and posture survey

Question Asked	Response †	The Number of Operators Who Provided the Response
What task were you performing when you had to adjust your posture in order see what you were doing or where you were going?	(1) Driving in reverse (to pick up a load)	2
	(2) Observing terrain while driving	3
	(3) Observing tires while driving	1
	(4) Monitoring the carried load	1
	(5) Observing axles while driving	1
	(6) Picking up a load	2
	(7) Ploughing	1
	(8) Adjusting the boom/load height for the grade driven over	1
How was your visibility impaired?	(1) (4) (6) (8) Couldn't view the load/rear of the vehicle	6
	(3) Couldn't view the tires	1
	(2) View of the terrain was limited	1
	(5) Couldn't view the axels	1
	(7) Couldn't view the load/front of the vehicle	1
What aspect of the cab design impaired your visibility?	(1) (3) (4) (8) Seat placement	3
	(3) Radio placement	1
	(2) Front fenders	1
	(5) Metal around the windows	1
	(5) A washer fluid container	1
	(6) Boom and Arch	1
	(7) Tires	1
	(6) Fuel tank	1
How did your impaired visibility affect you posture? Describe the posture of the neck, shoulders, truck, hips, and legs.	(1) (2) (3) (4) (6) (8) Rotate trunk	5
	(5) (6) (7) Trunk forward bend	2
	(6) (7) Trunk lateral bend	1
	(1) (2) Rotate neck	2

† The bracketed numbers indicate which responses were related.

Table 6: Summary of findings from a cab design and posture survey

Question Asked	Response †	The Number of Operators Who Provided the Response
Task Description	(1) Operating hand controls/grapple	2
Describe why you have to change your posture to manipulate the machine's controls during the task	(1) The hand controls are to the side of the seat	1
	(1) The hand controls are to the back of the cab	1
Describe the adopted posture of the neck, shoulders, truck, hips, and legs.	(2) Rotate trunk	2
	(2) Rotate neck	2

† The bracketed numbers indicate which responses were related.

4. DISCUSSION

Knowledge of operator trunk postures under field operating conditions and the influence of those postures on health will allow vehicle designers to create cab, seat and control designs that minimize harmful posture requirements. While driving their skidders, the operators in this study typically sat with a forward facing and slightly extended trunk accompanied by a large lateral bend. Instances of more extreme extension are believed to be the result of operators pushing their trunk into the backrest with their arms and legs in order to support themselves while driving over steep terrain and during WBV exposure. This stabilizing posture was associated with musculoskeletal symptoms for the neck, knees, ankles and feet. Operators who had musculoskeletal symptoms for the neck spent a larger proportion of their time extending or flexing their trunk to greater angles than the other operators under the majority of driving conditions. It was also interesting to note that the operators who spent the most time with a trunk flexed trunk (>10° while DL and DUL) reported the most severe musculoskeletal symptoms for the neck. Extending the trunk would result in the operators flexing the neck in order to view their driving routes, while flexing the trunk would result in neck extension by the operators. Extreme forward flexion of the cervical spine and static contraction of the neck and shoulder muscles to counteract the weight of the head are noted as causative factors for musculoskeletal symptoms of the neck by Magnusson and Pope (1998) [46]. Ariens et al. (2001) [47] found that working with a flexed neck for >70% of the work duration increased the odds for neck pain (although not significantly), and that flexion and rotation of trunk are potential confounding variables for neck pain. Harms-Ringdahl et al. (1986) [48] investigated the occipital-C1 and C7-T1 joint loading under combinations of occipital-C1 and C7-T1 flexion and extension, along with the muscle activity of various neck, shoulder and thoracic muscles. These researchers found that a combination of occipital-C1 and C7-T1 flexion increased the load on the C7-T1 joint by a factor of 3.6, and flexing the C7-T1 joint and extending the occipital-C1 joint resulted in a 3.1 times increase in load at the C7-T1 joint [48]. Increased joint loading can result in overexertion of tissues and increased cumulative loading, both of which are associate with increased risk of musculoskeletal injuries [49]. Harms-Ringdahl et al. (1986) [48] also found that median normalized electromyography (EMG) amplitudes were significantly increased in the trapezius and cervical erector spinae muscles when the C7-T1 joint was flexed and the occipital-C1 joint was extended [48]. Greater muscle activity is associated with increased muscle fatigue due to localized reductions in blood flow and the impairment of normal metabolic processes (i.e. oxygen uptake and metabolite removal), that can result in sensations of pain [49,50]. Therefore, increased joint loading and muscle activity may cause the neck pain reported by the operators in this study.

In addition, to neck symptoms, upper back symptoms were also related to trunk flexion in this study. The operator who reported upper back symptoms spent the greatest percentage of time DL, DUL, PUAL and ploughing with a flexed trunk. Flexing the lumbar spine relative to the sacrum may have been accompanied by some thoracolumbar spine and neck extension to view the driving route and load. Harms-Ringdahl et al. (1986) [48] found that thoracic erector spinae (TES) and rhomboids muscle activity was significantly increased when the neck was extended. O'Sullinvan et al. (2006) [51] found that thoracolumbar spine extension in order to maintain an upright sitting posture was also associated with significantly greater TES muscle activation. Hanson et al. (1991) [52] found increased muscle activity and fatigue in the TES muscles while sitting with a flexed trunk and exposed to vibration. It is interesting to note that Hanson et al. (1991) [52] had subjects flex 20° about the hip while vibrated, and the operator with the upper back pain here, spent the most time flexed 20°±5° about the hip while vibrated. Here, much like the neck, fatiguing contractions of the muscles in the upper back for extended periods of time may explain the upper back symptoms.

The trend towards a large lateral bend to the left was consistent among the skidder operators, with the exception of Operator 4 and 6 while DL, and Operator 5 when DUL. Less need for monitoring the load while driving may have allowed the operators to lean to the side, resting against the armrest as they drove. Conversely, an increased need to monitor the load may explain why Operators 4 and 6 spend less time in a deep LTB while DL. It is interesting to note that the operator who reported low back symptoms was found to spend the most time adopting a deep LTB during all operating conditions. Pope et al. (2002) [16] discuss how high levels of contralateral muscle activity occur to the direction of trunk rotation and lateral bending, and how muscle activity is small on the ipsilateral side. This asymmetric muscle activity, differentially load the joints and muscles of the low back. Prolonged and/or repeated differential loading can result in disproportionate demands on the various muscles surrounding a joint leading to different levels and rates of muscle fatigue [49]. If these patterns of fatigue are allowed to continue, the altered muscle kinetics may result in joint kinematics and loading that differ from the normal and optimal pattern for that joint, potentially leading to alterations in joint stability, stress concentrations, and injury [16,49]. It was also noted that the operator who reported low back symptoms spent the majority of time within two distinct flexion/extension postures while DOAL and two distinct TWST postures while DOAL and PUAL indicating frequent movement between these postures as the operator attempts to view the load and perform the required task. Repeated flexion and twisting of the spine can cause damage to the vertebrae and vertebral discs [53-55], and poses a risk for LBP. Static twisted trunk postures are also associated with LBP [8]. Although, no reports of ill health were associated with the tendency to TWST in this study, these postures were observed, with Operators 3 and 5 twisting to the right and Operator 7 twisting to the left while DL and DUL. Twisting in the range of 10°–15° involves little muscle effort, but beyond this region, increased muscle effort is required [9,56]. The aforementioned operators exceeded 15° of TWST more than 14% of the time when DL and 21% of the time when DUL. The increased muscle effort with TWST can be fatiguing and lead to pain.

The literature discussed thus far provides reasonable support for the association of the postures determined in the field with the musculoskeletal symptoms reported. In particular, the joint loading and muscle activity associated with the postures seen in these skidder operators can be linked to musculoskeletal injury, but the present study did not collect these types of data. Studies which include the collection electromyographic (EMG) data and the determination of joint loads should be conducted in the future to support the notion of joint loading and muscle activity as injury mechanisms in these operators. In addition, the present study was a preliminary investigation with limited time and funding. As a result only seven operators were tested, and although the data collected represents a large dataset, it is suggested that a greater number of operators be tested in the future so that the results can be more generalizable.

Table 5 and Table 6 reveal several aspects of the skidder designs that lead operators to twist their trunk and neck, LTB and flexing/extending their trunk. The repositioning of controls, cab frame components, working attachments, or any other object which would cause an operator to bend or twist in order to obtain the necessary field of view or operate the necessary controls for the task being preformed can help improve operator postures. Using computer simulation, Godwin et al. (2007) [14] found improvements in visibility and reductions in TWST, LTB, and neck rotation with the repositioning of the seat in an underground mining load-haul-dump vehicle. In the skidders studied here, the most common aspects of vehicle design that affected posture were the location of the hand controls and the seat location. The operators reported that the controls to operate the grapple were located to the side of the seat and rear of the cab, causing the operator to twist the trunk and neck to operate them. Relocating the controls from the side/rear of the cab to location in front of the operator would help alleviate the need for the operators to twist while operating those controls. However, the operators would still have to twist in order to view the loads while PUAL or DOAL. This is because the seats face towards the front of the vehicle and the operators need to twist the trunk and neck in order to view the rear of the vehicle where the grapple and load are located. Many skidders have seats that are rotated and not directly in line with the direction of vehicle travel, in order to reduce the magnitude of twisting required to view the rear of the vehicle, however, it appears that further improvements need to be pursued. The use of a swiveling seat and/or cab has been suggested by operators to aid in providing a comfortable working posture [10,13,57], as well as a decrease in head and trunk rotations [12,57]. Although a swiveling seat and/or cab may not be a viable solution for all forms of forestry equipment, they do demonstrate how operator postures can be improved through cab design.

5. CONCLUSION

The most immediate postural concerns for the health of the skidder operators were trunk flexion, extension and LTB. The relocation of controls from the side of the seat to the front, and improvements in operator visibility through the redesign of some cab elements and the seat will help reduce the risk of injury in these operators and improve ride comfort through improvements in operator posture.

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7. BIOGRAPHY

Robert Jack is a Ph.D. Candidate at the University of Guelph, studying Biophysics through the School of Engineering. His research interests are focused on investigating the interacting effects of 6-degree-of-freedom (DOF) whole-body vibration (WBV) exposures, muscle activity, and posture on the transmission of vibration throughout the spine. Other research projects have included the design of a 6-DOF seat pan transducer for WBV measurements, and novel goniometry methodologies for field posture measurements.