Applied Ergonomics 75 (2019) 129–133

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Occupational cranking operations: The scapula perspective

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ARTICLE INFO

Keywords:
Shoulders
Trucking
Musculoskeletal disorders
Best practice

ABSTRACT

Cranking the landing gear is a common task performed by truck drivers to raise or lower trailers. This task poses a risk to the shoulder joint due to the required forceful exertion and the posture constrained to the hand-handle interface. As a potential occupational risk, there has been no definitive guideline for best practices among truck drivers. An operator can crank perpendicular (frontal) or parallel (sagittal) to the crank rotation. In this laboratory study, the effects of cranking method and resistance on scapular range of motion and shoulder muscle activity were observed in 12 participants. Scapular posture was measured using an optical motion tracking system. EMG was monitored on 16 muscles contributing to shoulder movement. The results show that during frontal cranking, the scapular range of protraction was 28 ± 11.6°, which was more than the sagittal cranking (23 ± 10.4°), indicating a decreased subacromial space and elevated shoulder impingement risk. Seven muscles (all three deltoid muscles, middle trapezius, supraspinatus, infraspinatus, and teres minor) demonstrated that when the crank resistance was low, the front cranking method resulted in lower activity than the side cranking. When the crank resistance was 20 Nm, the muscle activity on these seven muscles was greater when cranking from the front than from the side. Based on these observations, we suggest that when the resistance is low (lowering the trailer) the driver should stand facing the trailer. On the contrary, it is advantageous to stand parallel to the trailer and crank while raising the trailer to apply the full body strength to reduce the shoulder load.

1. Introduction

Shoulder musculoskeletal disorders are among the most prevalent work-related musculoskeletal disorders. More than 70,000 injury and illness cases involving shoulders were recorded by Bureau of Labor Statistics in 2016 (Bureau of Labor Statistics, 2017). The yearly claim rate for shoulder disorder was 14.8 per 10,000 full time equivalents in the state of Washington from 2002 to 2010 (Anderson et al., 2015). Among them, 6.2 per 10,000 were attributed to rotator cuff syndrome. Overall, shoulder disorders resulted in a median lost time of 192 days per claim case, and the average direct costs per claim was $74,061 (Anderson et al., 2015).

Transportation was the number two industry sector for work related musculoskeletal disorders by claims incidence rate, only slightly lower than construction (Anderson et al., 2015). Following road and driving issues, the physical nature of the work was the second leading concern among drivers through a self-report survey (Friswell and Williamson, 2010). In fact, injuries resulting from physical effects are much higher in occurrence frequency (Lin and Cohen, 1997). Musculoskeletal disorders of the back, neck and upper extremity were the most common injuries across all trucking industries and occupations (Robb and Mansfield, 2007; Sekkay et al., 2018). Both trucking companies and truck drivers ranked musculoskeletal and slips, trips and falls injuries as the leading safety concerns (Spielholz et al., 2008). During a three-year injury data reporting program, overexertion was among the most frequent and severe type of injury reported among truck drivers (Lin and Cohen, 1997). Truck drivers perform various physical tasks that could lead to these injuries. For example, cargo handling (65%), and vehicle and terminal parts handling (31%) both contribute to the recorded cases categorized as overexertion injuries (Lin and Cohen, 1997). Cranking the landing gear to raise or lower trailers is an example of the vehicle handling tasks frequently performed by these workers.

The landing gear raises or lowers a trailer to allow for connecting or disconnecting to the fifth wheel of the truck. The system uses a hand operated crank and lever system and hence pose a demand on the upper extremity and the back. Although cranking is a common task in various industries, the current literature lacks systematic investigations to generate valid ergonomics guidelines regarding the proper operation techniques and the effect of crank operations on operators. Cranks are typically part of control or manual operations. They are found on large valves as part of an opening/closing mechanism (Schulze et al., 1997). They can also be found as tool handles, such as on corn/maize shellers in farms (Singh et al., 2012). Raouf and colleagues' investigation was probably the

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https://doi.org/10.1016/j.apergo.2018.09.011
Received 1 March 2018; Received in revised form 27 July 2018; Accepted 23 September 2018
Available online 03 October 2018
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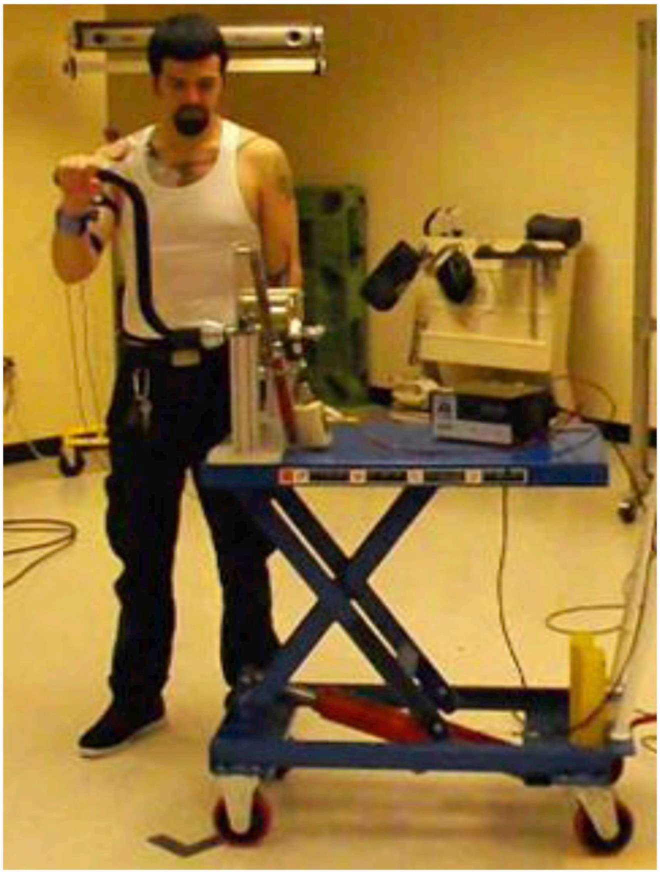

Fig. 1. Sagittal cranking posture.

earliest work done in the ergonomics field on continuous cranking motions (Raouf et al., 1984, 1986). They identified that clockwise turning was preferred to counterclockwise turning. Also, crank radius, torque, and plane angles significantly affected the operator performance. However, the operator posture or stance relative to the crank was not described throughout these papers. Schulze et al. (1997) demonstrated that in order to generate the greatest torque on a valve, a 0° plane angle, counterclockwise operation was recommended. Similar to Raouf et al., Schulze et al., failed to describe the operator stance and posture in sufficient details in the paper.

Due to the lack of scientific evidences, the current practices are mainly based on the opinions of subject matter experts. Currently, conflicting recommendations of operation methods exist in educational materials. One is cranking in the sagittal plane with the hand(s) holding the crank handle parallel to the driver's face as provided by (University of Waterloo) and simulated in Fig. 1. This cranking posture mostly utilizes the back to move the crank. The other is cranking in the frontal plane, with shoulders parallel to and facing the trailer, as simulated in Fig. 2. For example, the Trucking Injury Reduction Emphasis (TIRES) program of the State of Washington in the United States published a series of educational flyers (Washington State Department of Labor and Industries, 2010, 2014), where the photos illustrate a driver cranking the landing gear using the frontal cranking posture. The crank spindle is perpendicular to the body frontal plane. This cranking action is done mostly through shoulder rotations. This could put a demand to the shoulder. Since shoulder was among the leading musculoskeletal problems reported by truck drivers (Robb and Mansfield, 2007), the validity of such recommendation warrants further investigation.

Rotator cuff injuries, as the leading shoulder problem among truck drivers (Anderson et al., 2015), do not have precise pathogenesis. However, it is widely believed that certain extrinsic mechanic factor of the complex shoulder joint structure has an important role. The limited

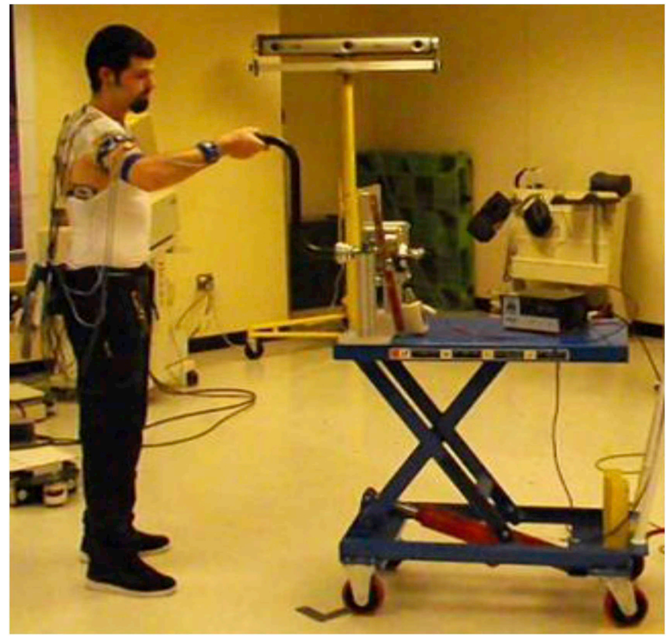

Fig. 2. Frontal cranking posture.

space created among the bones consisting of the shoulder joint can pinch the soft tissues. Rotator cuff syndrome could develop from repetitive exposures. The scapula, due to its role in shoulder joint and its posture relative to the humerus and the clavicle, is strongly related to this extrinsic factor for shoulder injuries.

While the movement of scapular is difficult to measure in vivo due to the anatomical structure of the scapula. Optoelectronics-based marker cluster has also been examined for identifying the motion of scapula (e.g., (Grewal et al., 2017; Xu et al., 2016). Using scapula locator-measured scapula orientation as the reference, it was found that an acromion marker cluster could provide a good estimate of scapula orientation when the humeral elevation angle was less than 100° (van Andel et al., 2009).

Therefore, the objective of this study was to systematically examine how landing gear operation (cranking) technique and resistance, which represents the load, affect scapular posture and shoulder muscle activities. The hypotheses were that both scapular posture and shoulder muscle activity would be affected by operation technique and the level of cranking resistance.

2. Methods

2.1. Participants

Twelve male participants were recruited from a local community for this study, which was approved by an accredited institutional review board. The participants were all healthy, and reported no existing musculoskeletal symptoms. After giving informed consent, their basic anthropometric measurements were taken. Their average (SD) age, weight and height were 34.8 (13.2) years, 87.8 (14.8) kg, and 180.2 (4.6) cm, respectively.

2.2. Apparatus

A cranking simulator was custom-built in the laboratory. The crankshaft (rotation center) was mounted on a leveled surface raised at 112 cm (44 inches) above the floor. This height was determined by averaging three randomly sampled trailers prior to the apparatus setup. The lever arm connected the handle and the crankshaft was 30 cm long. An electromagnetic particle brake was connected to the crankshaft to control the resistant torque by adjusting the input electrical current.

A custom system was designed to simulate a truck container landing gear cranking task performed in two different orientations. The hub, within which a rotational axis of a typical landing gear crank handle was coupled to the horizontally oriented shaft of a magnetic particle brake, was mounted to a rigid base. The brake, when energized, provided consistent torque in the form of friction to oppose the rotation of the crank handle applied by the participant. The experimental torque level was set using the electrical current controller of the magnetic particle brake. The torque level was determined by field measurement of the torque required to crank actual landing gear. A multi-turn potentiometer recorded angular displacement of the brake shaft, and thus the crank handle. A strain gauge load beam mounted between the rigid apparatus frame and the body of the otherwise unconstrained particle brake. In this configuration, the load beam opposed rotation of the particle brake body produced during the cranking operation, and as such provided a direct measure of the torque output created by the cranking operation. Both the potentiometer and load beam outputs were sampled in real-time at (100 Hz), and the output was stored in computer memory.

A motion tracking system (Optotrak Certus System, Northern Digital, Canada) was used to measure 3-D kinematics of the right scapula. Two marker clusters were attached to the body using adhesive tape (Fig. 3). One cluster was attached to the flat part of the acromion where the scapula spine meets the acromion process (van Andel et al., 2009 and Prinold et al., 2011), and the other one was attached on the thorax below the C7. Anatomical bony landmarks were digitized by a probe with the participants in an upright standing posture. The suprasternal notch (IJ), xiphoid process (PX), C7 vertebra, and T8 vertebra were digitized with respect to the marker cluster on the thorax; The acromial angle (AA), the root of the scapula spine (TS), and the inferior angle (AI) of the right scapula were digitized with respect to the marker cluster on the scapula.

Electromyograghy (EMG) signals were recorded using a wireless system (Noraxon Inc., Scottsdale, AZ, USA). Surface EMG around the shoulder area on the following 16 muscles: pectoralis major (clavicle), pectoralis major (sternal), anterior deltoid, middle deltoid, posterior deltoid, bicep, tricep, upper trapezius, middle trapezius, lower trapezius, supraspinatus, infraspinatus, serratus anterior, lattisimus dorsi, teres minor, and teres major was used to monitor muscle activities. Bipolar surface electrodes (Ag—AgCl, Noraxon Inc., Scottsdale, AZ, USA) were taped on each muscle on previously described locations (Basmajian and Blumenstein, 1980; Perotto, 2011) after skin preparation. The ground electrode was taped on the middle part of the clavicle. The signals were pre-amplified with a gain of 2000 and collected at a sampling rate of 1024 Hz.

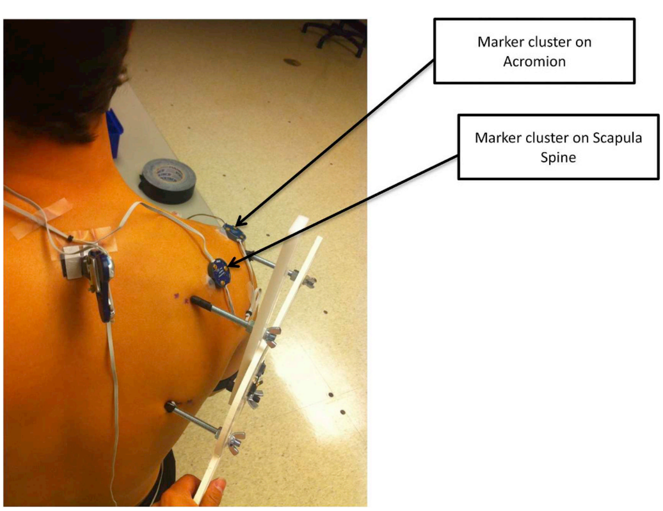

Fig. 3. The scapula orientation was measured using the marker clusters on acromion and scapula spine.

2.3. Procedures

The reference voluntary contraction (RVC) for each muscle was utilized for normalization of the surface EMG signals (Xu et al., 2014). The participant held a 3-kg metal bar in the right hand assuming three postures for the RVC tests. For the first posture, the shoulder abducted 90° in plane of scapula, elbow extended and internally rotated to the thumb down direction. For the second posture, shoulder was 90° abducted in the scapular plane, elbow in 90° flexion and thumb pointed towards their body. In the third posture, the participants bent forward close to 90° and leaned on a surface with the left hand. Right arm extend backward, roughly with the upper arm aligned with the upper body, with palm facing the sagittal plane.

The participants then were briefed about the protocol, and were given practices to operate the crank. They were free to choose their comfortable foot stances for each of the two prescribed working postures (Figs. 1 and 2). The order of the two postures was alternated, and hence balanced, among the participants. When ready, the crank was set at the top position, and the participants were instructed to rotate the crank for five complete cycles. The direction was clockwise, same as the actual landing gear operation to lift a trailer.

2.4. Data design and analysis

The independent variables were resistance (0, 10, and 20 Nm) and cranking method (sagittal and frontal). The dependent variables were scapular range of motion in three directions: rotation, protraction/retraction, and tilt (Wu et al., 2005), and average EMG amplitudes of the 16 rotator cuff muscles (Xu et al., 2014).

During offline data processing, the anatomical coordinate systems of thorax and scapula were created from the measured bony landmarks based on ISB recommendations (Wu et al., 2005). Scapulothoracic joint angles during the cranking tests were then decomposed using the Euler angle sequence recommended by the ISB (Wu et al., 2005).

All EMG signals were band-pass filtered with a 10–400 Hz, 4th order Butterworth zero-lag filter (van Dieen and Kingma, 2005). Once filtered, the signals were rectified and low-pass filtered with 2.5 Hz. For each muscle, the highest magnitudes obtained among the three RVC tests was used as the normalization reference. For all the cranking trials, the EMG signal of each muscle was then normalized to the maximum muscle activity of this muscle collected during the RVC trials.

Scapular ranges of motion (rotation, protraction/retraction, and tilt, as defined in Wu et al., 2005) were analyzed independently. Analysis of variance (ANOVA) was performed to test the effects of resistance, cranking method, and their two-way interaction on the scapular ranges of motion during cranking tasks and on the muscle activity of the rotator cuff muscles. The participant was treated as a random variable. The test *p*-value was set at 0.05. Statistics analysis was performed using SPSS v. 18 (IBM, Armonk, New York, USA).

3. Results

3.1. Scapular range of motion

The effects of cranking method and resistance on scapular postures are summarized in Table 1. When cranking from the side, the scapular range of rotation was 30 ± 9.0°, which was more than from the front (24 ± 9.7°). The range increased from 25 ± 8.7° to 29 ± 10.5° as the resistance increased from no load to 20 Nm. For the range of protraction/retraction, it was more for the front cranking method (28 ± 11.6°) than for the side cranking method (23 ± 10.4°). For scapular tilting, the front cranking method resulted in a less range (10 ± 5.0°) than side cranking (18 ± 9.3°). Resistance level was not a significant factor for the protraction/retraction and tilt ranges. The method*resistance interaction was not significant for all scapular ranges of motion.

Table 1
P-values from the ANOVA analyses of the effects of cranking posture and resistance on scapula range of motion. Significance level was set at $p < 0.05$. The effect trend is noted in parentheses. Their two-way interaction was included in the statistical model. However, it was not significant for any of the scapular ranges of motion, and hence omitted in this table.

Scapula motion[a]	Posture	Resistance[c]
Rotation	* < **0.001** (Sagittal > Frontal)	***0.021** (20 > 10 > 0)
Protraction/ Retraction[b]	* **0.004** (Frontal > Sagittal)	0.197
Tilt	* < **0.001** (Sagittal > Frontal)	0.074

[a] Defined according to International Society of Biomechanics (ISB) standard (Wu et al., 2005).
[b] Also known as internal/external rotation in various publications.
[c] Resistance levels were 0, 10, and 20 Nm.

3.2. Shoulder muscle activity

The resistance level was a significant factor for activity on all 16 muscles under investigation. The muscle activity on seven muscles was not affected by the cranking method (Table 2). For the affected muscles, triceps and teres major had higher activity when cranking from the side, while the seven others had higher activity when cranking from the front.

The cranking method and resistance interaction was a significant factor for activity on eight of the muscles monitored. Except for one where the trends of the two independent variables did not intercept within the test range, seven muscles (all three deltoid muscles, middle trapezius, supraspinatus, infraspinatus, and teres minor) exhibited the trend that when the crank resistance was little, the frontal cranking method resulted in lower activity than the sagittal cranking. Frontal cranking resulted in greater muscle activity on these same seven muscles than side cranking when the crank resistance was 20 Nm.

Table 2
ANOVA analysis of the effects of cranking posture and resistance on muscle activity. Significant effects of Posture and posture × Resistance on muscles are denoted with asterisks and the effect directions in parentheses. Resistance was a statistically significant factor for muscle activity on all muscles; therefore, it is omitted in the table.

Muscle	Posture	Posture × Resistance Interaction[a]
Pectoralis (clavicle)	* (Frontal > Sagittal)	
Pectoralis (sternal)	* (Frontal > Sagittal)	*(Not intersected within this range)
Deltoid (Ant)	* (Frontal > Sagittal)	*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Deltoid (Med)		*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Deltoid (Pos)		*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Biceps	* (Frontal > Sagittal)	
Triceps	* (Sagittal > Frontal)	
Trapezius (upper)		
Trapezius (middle)	* (Frontal > Sagittal)	*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Trapezius (lower)	* (Frontal > Sagittal)	*(No intersected within this range)
Supraspinatus		*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Infraspinatus	* (Frontal > Sagittal)	*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Serratus Anterior		
Latissimus Dorsi		
Teres Minor		*(0: Sagittal > Frontal, 20: Frontal > Sagittal)
Teres Major	* (Sagittal > Frontal)	

[a] Resistance levels were 0, 10, and 20 Nm. Interaction trends are denoted with the comparison between the postures at the no load (resistance = 0) and the high load (resistance = 20 Nm) levels.

4. Discussion

This is the first study designed to record and examine the biomechanics of realistic cranking tasks involving shoulder rotations. Sporadically, the biomechanics of cranking activities that require upper extremity rotational movements have been examined in previous studies, such as hand-cycling for rehabilitation and sports sciences (Bressel et al., 2001; Suzuki et al., 2011), efficiency for grinders in yacht racing (Neville et al., 2010), or softball pitching (Escamilla and Andrews, 2009). However, none of those movements bears the similarity to the whole arm rotation that relies mostly on the shoulder joint (frontal cranking) or the back (sagittal cranking).

In a review article summarizing extrinsic factors of rotator cuff injuries, it was proposed that 95% of rotator cuff injuries resulted from the mechanical compression of the tendons under the coraco-acromial arch (Mehta et al., 2003). Impingement is the result of a narrow subacromial space, which is dependent on the interplay of the major shoulder bones, and among them, the kinematics of scapular plays an important role (Ludewig and Reynolds, 2009). The scapular kinematics were assessed in vivo in various daily living activities (Hall et al., 2011) and wheelchair propulsion (Morrow et al., 2011) as surrogates to shoulder injury risk indications. This study monitored scapular kinematics in realistic cranking operations to assess the demands in two different postures.

When an operator performs a frontal cranking, it relies almost solely on the rotation of the whole arm in front of the body, with the shoulder joint as the center. On the other hand, for sagittal cranking, once the arm pushes forward to the reach limit, the back needs to bend to continue the crank rotation. Two rotation centers are involved: shoulder and low back. The difference in the nature of the movements resulted in different manifestation on the shoulder and hence the scapula kinematics. The results show that the range of motion for scapular protraction was greater and the posterior tilting was less during frontal cranking than during sagittal cranking, According to Solem-Bertoft et al. (1993), as the shoulder moves from a retracted to a protracted position, the subacromial space narrows. Michener et al. (2003) further suggest that because scapular posterior tilting elevates the anterior acromion, the subacromial space improves as a result. This implies that smaller posterior tilting is less beneficial. Considering both shoulder posture criteria, sagittal cranking should pose less impingement risk than frontal cranking, regardless of the resistance level.

Because all the participants were healthy adults without shoulder issues, the muscle activities recorded using electromyography mostly represented the muscle forces required to complete the cranking movements. As expected, the muscle activity was affected by the resistance. The higher the resistance, the greater the activity was found in all muscles contributing to the cranking motion, regardless of the posture used. Further, the significant cranking posture*resistance interaction on 7 of the 16 monitored muscles demonstrated that the shoulder muscle contributed more during frontal cranking when the resistance was at the higher level. For sagittal cranking, the back can assist the movement by flexing and hence reduce the load on the shoulder. While Schulze et al. (1997) never specified the cranking posture used in their study, examining through the text, it was possible that the participants used sagittal cranking similar in our study. In their Discussion they concluded “the crank handle located parallel to the corneal plane of the participant allows operators to use their entire body to produce greater rotation torque.” (p. 39). On the other hand, for frontal cranking, the crank rotation center is perpendicular to the truck-flexing plane so the shoulder is solely responsible for torque exertion to rotate the crank, and hence all load is imposed on the shoulder.

The literature still has no definitive association between scapular postures and subacromial space. For example, in a cadaver study Karduna et al. (2005) found that scapula tilt and protraction had no effect on subacromial space, which is contradicting to many findings in the literature. Therefore, it is difficult to determine the better cranking practice from scapular posture perspective alone at this moment. Further research is needed in this area. Nonetheless, it is possible to conclude between the two cranking methods from the shoulder muscle perspective: when there is no load, frontal cranking is better; when there is a load (resistance), sagittal cranking would result in a lower muscle load. Because the pathogenesis of shoulder injuries is varied, and difficult to confirm clinically, our discussion relied solely on the knowledge derived from previous studies. That is, the scapular posture influences sub-acromial space, and hence the risk of shoulder impingement and rotator cuff syndrome. Nonetheless, should the hypothesis be altered, the current dataset can be used to determine the impact of cranking posture for appropriate recommendations.

Further, there are also perspectives other than biomechanics to consider during landing gear operation based on anecdotal reports from professional truck drivers. For example, sagittal cranking is not recommended because of the risk that the hand may slip off the handle and the resistance tension may jerk the handle back, hitting the driver in the face. Space constraint also occurs in a crowded trailer parking lot when units are parked close to each other. Sagittal cranking would be the only option because no space is available to perform frontal cranking. While addressing these other issues is beyond the scope of the current biomechanical investigation, they are also important determinants for safe landing gear operation.

One limitation of this study was that only one cranking direction, clockwise, when viewed facing the rotation spindle, was tested. While this represents the rotation to lift up the trailer, the use of muscles and joints to crank in the other direction may be different. Therefore, future investigation is warranted for a complete understanding of all potential exposures in landing gear operation.

5. Conclusion

This study evaluated the posture effect on the shoulder load during truck landing gear operations. Scapular kinematics and muscle activity were collected on 12 participants. Based on the analysis, we suggest that when the resistance is low, i.e. lowering the trailer, the driver should stand facing the trailer and crank the handle frontally. While raising the trailer, it is better to stand parallel to the trailer and crank sagittally to use full body strength to reduce the shoulder load.

Acknowledgments

The authors would like to thank Raymond McGorry for assistance in apparatus design and help in the manuscript preparation. The authors are also grateful for assistance in data collection from Jacob Banks, Niall O'Brien, and Amanda Rivard, and for comments from Jena Cole and Caroline Smith. This study was conducted at Liberty Mutual Research Institute for Safety before its closure in 2017.

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