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Analysis of physical demands during bulk bag closing and sealing

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Abstract

Several tools are sold and recommended for closing and sealing flexible intermediate bulk containers (bulk bags) which are used to transport product that has been mined and processed. However, there is limited information on the risks, physical demands, or the benefits of using one tool over another. The purpose of this study was to evaluate the physical demands involved with two closing methods and several sealing tools in order to provide recommendations for selecting tools to reduce exposure to risk factors for work-related musculoskeletal disorders. In this study, twelve participants completed bag closing and sealing tasks using two different closing methods and eight sealing tools on two types of bulk bags. Physical demands and performance were evaluated using muscle activity, perceived exertion, subjective ratings of use, and time. Results indicate that using the “flowering” method to close bags required on average 32% less muscle activity, 30% less perceived exertion, 42% less time, and was preferred by participants compared to using the “snaking” method. For sealing, there was no single method significantly better across all measures; however, using a pneumatic cable tie gun consistently had the lowest muscle activity and perceived exertion ratings. The pneumatic cable tie gun did require approximately 33% more time to seal the bag compared to methods without a tool, but the amount of time to seal the bag was comparable to using other tools. Further, sealing a spout bulk bag required on average 13% less muscle activity, 18% less perceived exertion, 35% less time, and was preferred by participants compared to sealing a duffle bulk bag. The current results suggest that closing the spout bag using the flowering method and sealing the bag using the pneumatic cable tie gun that is installed with a tool balancer is ergonomically advantageous. Our findings can help organizations select methods and tools that pose the lowest physical demands when closing and sealing bulk bags.

Keywords

Bulk bag; Flexible intermediate bulk container; Bagging; Tools; Physical demand

1. Introduction

The prevalence of work-related musculoskeletal disorders (WMSDs) of the upper extremity is increasing (Houvet and Obert, 2013). Injuries associated with the upper extremities and trunk accounted for over 50% of all nonfatal mining injuries in 2010 (Smith, 2013).

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Repetitive motion cases are among the top 10 leading causes of occupational injury, and direct costs associated with these injuries are estimated to be almost $2 billion per year (LIberty Mutual Research Institute for Safety, 2014). Flexible intermediate bulk containers (hereafter referred to as bulk bags) are commonly used by mines to store and transport materials, and the processes of closing and sealing bulk bags rely heavily on the upper extremities. Overexertion was common (23%) among operators of bag filling stations and the injuries typically affected the upper extremity, with finger (50%) and hand (10%) injuries being the most common (Mine Safety and Health Administration, 2004–2008). Further, these tasks can require awkward postures and repetitive motions, which can contribute to WMSDs (Gallagher and Heberger, 2013; Houvet and Obert, 2013). Despite the associated risk factors, methods used to close and seal bulk bags have not been evaluated from an ergonomics standpoint.

Bulk bags are closed by gathering the bag material together and sealed by securing the material using either a string, plastic cable/zip ties, or metal wire ties (heavy duty coated metal twist ties with loops at the end to aid coiling). Often, bags are fabricated with a built-in string that can be used to seal the bags, but many tools are sold and recommended for sealing bags when cable/zip and wire ties are used. Strings are generally tied by hand (e.g., in a knot or bow), cable ties can be secured either by hand or with several types of cable tie guns (e.g., trigger gun or pneumatic gun), and wire ties are twisted closed with the use of a mechanical device.

Though there has been limited research on the types of tools used to seal bags, risk factors such as awkward postures, forceful exertions, and repetition have been shown to be associated with the occurrence of WMSDs (Armstrong et al., 1993; Gallagher and Heberger, 2013). A series of two studies evaluated methods of closing wire ties (Li, 2002, 2003) and compared the traditional use of pliers to twist wires to various alternative methods, including a non-powered wire tying hook and a novel wire tying hand tool, as well as several attachments for a powered screwdriver. These studies found reduced forearm muscle activity and deviated postures and increased subjective ratings with the alternative methods, which required less repetitive motions and awkward postures of the hand and wrist. Another study compared the use of plastic cable ties and wire ties during two different construction tasks (Gangakhedkar et al., 2011). Finding indicated reduced muscle activity and reduced time when using cable ties versus wire ties, likely because of the requirement to twist wire ties compared to cable ties that do not need to be twisted closed. To the authors' knowledge, no other studies have specifically evaluated tools available to seal bulk bags.

The purpose of this study was to evaluate the physical demands associated with several observed methods of bulk bag closing and sealing in order to provide guidance on selecting methods to reduce exposure to risk factors for WMSDs. Performance and physical demands were quantified using task completion time, muscle activity, subjective exertion ratings, and subjective assessments of the closing and sealing methods. Bag closing and sealing were evaluated separately in two experiments, each of which was performed in a controlled laboratory setting.

2. Materials and methods

2.1. Participants

Twelve participants (8 male, 4 female) were recruited using convenience sampling and all completed the study. Mean (standard deviation) age, stature, and body mass were 41.9 (8.6) years, 180 (7) cm, and 81.8 (11.2) kg for males, and 31 (4.8) years, 170 (6) cm, and 61.8 (5.0) kg for females. Participants were all right-hand dominant, self-reported having no recent history of musculoskeletal injury, and completed an informed consent procedure approved by the NIOSH Institutional Review Board.

2.2. Experimental design and equipment

Two experiments were conducted independently to evaluate bag closing and sealing. Each experiment used a full-factorial repeated measures design.

2.2.1. Experiment 1: bag closing—The first experiment evaluated bag closing, and participants completed four conditions with two levels of bag type (duffle and spout; Fig. 1) and two levels of closing method (snaking and flowering; Fig. 2). The bags were made of woven polypropylene, mounted from the four corners, rested on the ground and stuffed with empty boxes to simulate being full of material, as they would commonly be at bagging operations (Fig. 1). Material in the bag did not interfere with the closing and sealing tasks studied. Spout and duffle bags were chosen as they represent extremes in the amount of material at the top of the bag that would need to be gathered during closing and they are commonly used in the mining industry. The two types of bulk bags were procured from one bulk bag manufacturer (AmeriGlobe FIBC solutions, Lafayette, LA) and both bags included an attached liner inside of the outer bag. For Experiment 1 only the outer bag material was closed and not the liner, as observed at mines. The terms used for closing—"snaking" and "flowering"—were coined by the research team to describe commonly observed techniques used for closing bulk bags in mining. When using the snaking method, the bag material is twisted and then folded over on itself, while the flowering method involves gathering the bag material at the center (Fig. 2).

2.2.2. Experiment 2: bag sealing—The second experiment evaluated bag sealing. Participants completed sixteen conditions with two levels of bag type (duffle and spout, Fig. 1) and eight levels of sealing methods (built-in string, built-in drawstring, B-lock, manual cable tie, cable tie gun, pneumatic cable tie gun, pull twist tool, and screwdriver hook, Fig. 3). Sealing methods were selected based on those commonly observed in the mining industry. Specifications for the equipment used for sealing were B-lock (Syn-Tex, Winnipeg, Manitoba, Canada), 15-inch (38.1 cm) (Bag Corp, Dallas, TX) and 28-inch (71.1 cm) cable ties (Cable Ties and More Inc., Cheyenne, WY), cable tie gun (Hellermann Tyton, model MK9, Panduit, Tinley Park, IL), pneumatic cable tie gun (Hellermann Tyton, model MK9P, Panduit, Tinley Park, IL), and pull twist tool (Bag Corp, Dallas, TX) to be used with wire ties (16 gauge PVC coated steel, American Wire Tie Inc., North Collins, NY).

The B-Lock was similar to the string attached to the bag, but eliminated the need to tie a knot to secure the bag; however, the B-Lock required the catch (back rectangular part of the

B-lock shown in Fig. 3) to be pressed tight against the bag (Fig. 4). The manual cable ties were fastened by hand without the use of any tool. Tightening the cable tie using the cable tie gun was facilitated by the user depressing the lever/trigger repeatedly. The pneumatic power actuated trigger on the pneumatic cable tie gun results in a substantially reduced force requirement as compared to manually depressing the lever/trigger repeatedly on the cable tie gun. The pull twist tool was operated by looping the hook at the end of the tool into the loops of the wire tie and pulling the handle repeatedly (Fig. 4).

In addition to commercially available sealing equipment, a novel tool that can be used with wire ties was developed (screwdriver hook, Fig. 3). The tool consists of a powered screwdriver (Makita, model 6722D, Aichi, Tokyo) with a hook attached to the end that can loop through the ends of the wire tie. As the screwdriver spins the hook, the wire tie is twisted closed. This tool was designed to overcome some perceived limitations of the pull twist tool, namely the non-neutral postures observed anecdotally and force required to operate the pull twist tool (Fig. 4).

For the second experiment, the bag was closed using the flowering method (Fig. 2). The same sealing methods were used for the two bag types, although longer wire ties and cable ties were used for the duffle bag (28-inch, 71.1 cm) compared to the spout bag (15-inch, 38.1 cm) due to the larger volume of bag material. To ensure consistent sealing across sealing methods, the string, drawstring, B-lock, cable ties and wire ties were marked to indicate the final closing diameter that needed to be achieved. Each participant completed experiment one followed by experiment two, and within each experiment the presentation order of the treatment conditions was randomized.

2.3. Experimental protocol

Once informed consent was obtained, basic demographics, including gender, age, height, and weight were collected (Table 1). The task of closing bulk bags and sealing bulk bags using tools, as observed in practice, is hand intensive with operators often working with their shoulder flexed and abducted and the elbow flexed. Electromyography (EMG) electrodes were then be applied to the participants' skin on muscles that would be commonly utilized to achieve the observed postures including the trapezius, anterior deltoid, medial deltoid, biceps brachii, extensor digitorum, and flexor digitorum superficialis muscles on both the right and left sides (Fig. 5). The skin was cleaned and lightly exfoliated using an alcohol swab, and electrodes were applied once the skin had dried. A pair of pregelled self-adhesive Ag/AgCl electrodes (2-cm electrode separation) were placed on the belly of each muscle, and ground electrodes placed on the clavicle. Electrode placement on the belly of the muscles was as described in Criswell (2010). All EMG data was collected using a Noraxon wireless 16 channel data recorder (Model number: TM2400T, Noraxon U.S.A., Inc. Scottsdale, Arizona).

A 20-minute period for electrode stabilization followed, during which a live demonstration of each of the closing and sealing tasks was provided. Participants were allowed to practice each of the closing and sealing tasks at least once, or until they were comfortable performing the tasks. Baseline EMG measures were then collected that included a 30-s resting trial during which participants stood in a relaxed posture with their arms at their side. Three reference voluntary exertions (RVE) were performed, each isolating different muscles. The first RVE isolated the trapezius muscles, anterior deltoid, and medial deltoid muscle, and was performed in a seated posture with the right and left shoulder abducted 90° in the coronal plane, elbows fully extended, wrists straight, and palms down (Jackson et al., 2009; Mathiassen et al., 1995). The second RVE isolated the biceps brachii, and was performed in a seated posture with the right and left elbow flexed 90° with the wrists straight, palm facing upwards, and a 2-pound weight in each hand. The third RVE isolated the extensor digitorum and flexor digitorum superficialis, and was performed in a seated posture with the right and left elbow flexed 90°, the wrist semi-pronated, and the hand gripping a dynamometer (Inline Scientific Hand Dynamometer, Noraxon U.S.A. Inc., Scottsdale, AZ). During this RVE, participants were asked to exert 80 N of force and visual feedback was provided of the current and target force output (MyoTrace 400, Noraxon U.S.A. Inc., Scottsdale, AZ). The RVE was done for the right and left arms separately. Each RVE trials was 20-s and was repeated four times; a 40-s rest period was provided in between each of the four trials. The RVE was used to normalize the EMG data by dividing the EMG values for each muscle by the average of the four RVE trials for that specific muscle (Jackson et al., 2009).

In Experiment 1: Bag closing, participants were instructed to gather the outer material of the bag, and not the liner, using the assigned closing method at a comfortable pace. The task was deemed complete when the bag material was fully gathered as shown in Fig. 2. In Experiment 2: Bag sealing, the required tool was placed on a table to the right of the participant and participants were asked to close the outer bag and liner together using the flowering method before sealing the bag using the assigned sealing method. The task was deemed complete when the bag had been completely sealed to the requisite circumference(18.5 cm for the spout bag and 27 cm for the bulk bag; marked clearly on the string, drawstring, B-lock, cable tie and wire tie) and the sealing mechanism was securely in place. If any of the tasks were not completed correctly, the participant was asked to repeat the task. A rest period was provided between experiments of approximately 5 min. In addition, a rest period was provided between trials of approximately 2–3 min while the bags were reopened and the tools needed for the following trials were set up.

Each task was timed from the time the researcher instructed the participant to start until the task was deemed complete. After each task had been completed successfully, participants were asked to provide subjective perceived exertion ratings and complete a subjective rating questionnaire. Perceived exertion ratings were collected using the Borg CR-10 scale (Borg, 1982) (from 0 (nothing at all) to 10 (maximal) with the option to go higher if necessary (absolute maximum)) for the upper back, shoulder, upper arm, lower arm, wrist, and hand for both the right and left side. The subjective rating questionnaire included statements related to the ease of use (I completed the task easily using this tool/method), speed at which the task can be completed (I completed this task quickly using this tool/method), comfort during the task (I feel comfortable using this tool/method to complete the task), and whether or not they would use the method in the future to complete the task (I would use this tool/ method in the future to complete the task). Responses for all subjective questions were recorded on a 6-point Likert scale (strongly disagree to strongly agree). Lozano, García-Cueto and Muñiz (2008) found that scales with 4–7 responses had the highest reliability and validity.

2.4. Analysis

The EMG signals were hardware filtered using a low-pass filter with a 500 Hz cutoff. Raw EMG signals were filtered using a 3–500 Hz fourth-order band-pass filter, full wave rectified, and noise (zero offset) was removed. A 3 Hz fourth-order low-pass Butterworth filter was applied before data was normalized to each participant's RVE for individual muscles as described earlier. All data was processed in Matlab (Mathworks, Natick, MA). Mean muscle activity values in percent RVE for each trial were used for further analysis.

A repeated measures (within subjects) multivariate analysis of variance (MANOVA) procedure was used to compare differences in perceived exertion ratings and muscle activity for the left and right sides for closing tasks. A repeated measures (within subjects) analysis of variance (ANOVA) procedure was used to compare differences in time for closing tasks and time, perceived exertion ratings, and muscle activity for sealing tasks. The significance value was set to 0.05, except when analyzing perceived exertion ratings and muscle activity for sealing tasks, where the significance value was set to 0.01 to account for multiple comparisons as multivariate tests could not be conducted due to the limited sample size. If the assumption of sphericity was violated, the conservative Greenhouse-Greasier statistic was used with adjusted degrees of freedom. All statistical analyses were carried out in SPSS version 19 (IBM SPSS Inc., Chicago, IL) and post-hoc tests were conducted using Bonferroni's correction factor (Johnson and Wichern, 1992).

3. Results

3.1. Experiment 1: bag closing

3.1.1. Time—Repeated measures ANOVA indicated a significant difference in closing time for bag type ($F_{1, 11} = 21.50$, $p = 0.001$) and closing method ($F_{1, 11} = 175.19$, $p = 0.002$) with no significant interaction. On average, closing the duffle bag took 15.7% (1.7 s) longer than the spout bag, and snaking took 42.7% (4 s) longer than flowering.

3.1.2. Electromyography—Repeated measures MANOVA indicated a significant effect of closing method on muscle activity for the left ($F_{6, 6} = 4.76$, $p = 0.04$) and right ($F_{6, 6} = 5.90$, $p = 0.024$) sides, with no significant difference between bag types and no significant interactions between bag type and closing method. Post-hoc tests indicated that flowering involves a significantly lower muscle activation (on average 32% less muscle activity) as compared to snaking for all muscle groups investigated. Table 2 shows the mean and standard deviations for muscle activity in percent RVE for each muscle and post-hoc test statistics for closing methods.

3.1.3. Subjective assessments—Repeated measures MANOVA indicated no significant differences between conditions for perceived exertion ratings when individual body parts were considered separately, potentially due to high correlations in the perceived exertion ratings between neighboring body parts. However, when the perceived exertion ratings for body parts on the right and left side were averaged, there was a significant repeated multivariate effect of closing method ($F_{2, 10} = 5.38$, $p = 0.026$), with follow-up univariate tests revealing a significant difference in perceived exertion ratings on the right side for closing method ($F_{1, 11} = 9.64$, $p = 0.01$) (Fig. 6). For the right side, flowering had a lower perceived exertion rating (1.0) as compared to snaking (1.4). For the four subjective measures of interest (ease of use, comfort, speed, and future use) on average there was a 0.8-point difference between the best and worst condition, with flowering the spout bag being the best and snaking the duffle bag being the worst.

3.2. Experiment 2: bag sealing

3.2.1. Time—Repeated measures ANOVA indicated a significant difference in sealing times for bag type ($F_{1, 11} = 74.059$, $p < 0.001$), with the duffle bag (36.7 s) taking approximately 35.3% longer to seal than the spout bag (23.7). There was also a significant difference in sealing times for sealing method ($F_{7, 77} = 36.261$, $p < 0.001$). Post-hoc comparisons indicated that using a tool (cable tie gun, pneumatic cable tie gun, pull twist tool, or screwdriver hook) took significantly longer (36.2 s) than not using a tool (string, drawstring, B-lock, and manual cable tie) (24.2 s) with no differences within those groups. A significant interaction was also found between bag type and sealing method for sealing time ($F_{3.75, 41.23} = 4.634$, $p = 0.004$). Although the duffle bag took longer to seal as compared to the spout bag, the difference between duffle and spout was greater for some sealing methods as compared to others as seen in Fig. 7.

3.2.2. Electromyography—Repeated measures ANOVA for individual muscles indicated significant interactions between bag type and sealing method for the left trapezius and the left and right medial deltoid and extensor digitorum (Table 3). On further investigation, it was identified that bag type had a greater effect on some sealing methods as compared to others, with the spout bag yielding lower muscle activity values as compared to the duffle bag. For example, the spout bag had a lower muscle activity for the right and left medial deltoid as compared to the duffle bag for all sealing methods, but there was a greater difference between the two bag types for the string, drawstring, and pull twist tool as compared to the other sealing methods. There was a significant effect of bag type for most muscles (Table 3), except for the left anterior deltoid, biceps brachii, and extensor digitorum and right anterior deltoid. On average, the spout bag had 12.8% lower muscle activity as compared to the duffle bag. There was a significant effect of sealing method for nearly all muscles, except the right anterior deltoid, biceps brachii, and flexor digitorum superficialis (Table 3). Although post-hoc tests using Bonferroni's correction indicated that there was no one sealing method that produced a significantly lower muscle activity across all muscle groups studied, the cable tie gun and pneumatic cable tie gun yielded consistently lower muscle activity for the left hand and were 24% and 21% less than the other tools, respectively. There was a similar trend for the right hand, with the cable tie gun and pneumatic cable tie gun yielding 7% and 12.5% less muscle activity as compared to the other tools, respectively (Fig. 8). The pneumatic cable tie gun did produce higher muscle activity values for the right anterior deltoid (approximately 20% higher). Similarly the cable tie gun produced higher muscle activity values for the right anterior deltoid (approximately 24% higher), and right flexor (approx. 22% higher) and extensor digitorum (approximately 8.5% higher) muscles (see Fig. 8).

3.2.3. Subjective assessments—Repeated measures ANOVA for individual body parts indicated no significant interactions between bag type and sealing method for perceived exertion ratings (Table 4). In addition, bag type did not have a significant effect on perceived exertion ratings for any body part other than the right wrist, for which the perceived exertion ratings values were lower for the spout bag as compared to the duffle. In general, mean perceived exertion ratings values for the spout bag were 0.2 points (18% less) than the duffle bag. There was a significant effect of sealing method on perceived exertion ratings for some body parts (Table 4). Post-hoc tests using Bonferroni's correction indicated significant differences between sealing methods for some body parts, with all sealing methods that use tools (cable tie gun, pneumatic cable tie gun, pull twist tool, and screwdriver hook) producing lower perceived exertion ratings as compared to the drawstring for the left hand. The cable tie gun and pneumatic cable tie gun produced lower mean perceived exertion ratings compared to the manual cable tie for the right upper arm (Fig. 9). The pneumatic cable tie gun had the lowest perceived exertion rating on average (0.9) across all muscle groups and was, on average, 40% less than the other methods. The screwdriver hook (1.1) and manual cable tie gun (1.2) yielded the next lowest perceived exertion values (Fig. 9).

For the subjective measures of interest (ease of use, comfort, speed, and future use) there was a 0.7 point difference, on average, between the spout bag and duffle bag, with the spout bag yielding a higher score, indicating it was more useful. For sealing methods, the pneumatic cable tie gun stood out with a mean score of 5.0 for ease of use, 4.8 for speed, 5.1 for comfort, and 4.8 for future use. The cable tie gun and manual cable tie came in a close second and third, with the B-lock and drawstring being rated the lowest.

4. Discussion

The purpose of this study was to evaluate the physical demands associated with observed methods of closing and sealing bulk bags. Physical demands and performance were evaluated for closing and sealing and quantified using muscle activity, perceived exertion ratings, subjective assessments, and task completion times. Results indicated significant differences between closing and sealing methods investigated.

For closing bags, a lack of significant difference between the two bags indicated that the amount of material at the top of the bag did not have an effect on physical demands. However, non-significant subjective assessments indicated that users may perceive spout bags, which have less material, to be easier, quicker and more comfortable to close. As anticipated, the snaking technique produced significantly higher physical demands compared to flowering, based on both EMG and perceived exertion ratings, due to the increased complexity of the task that involving both twisting and gathering material at the top of the bag. The congruence of the objective (EMG) and subjective (perceived exertion ratings) measures of physical demands lends credence to the finding that flowering is less physically demanding than snaking. In practice, the effectiveness of the closing method, in terms of material leaking out or external contaminants entering the bag, would need to be considered and evaluated in addition to physical demands. Anecdotal evidence indicates that snaking produced a better seal as compared to flowering; hence, there may be a tradeoff between physical demands and closing effectiveness.

For sealing bags, there was a significant difference between bag types, indicating an influence of the amount of bag material at the top of the bag—especially for completion time and muscle activity for the dominant hand. It took on average 24.2 s to seal the spout bag, with less material at the top, as compared to 36.2 s to seal the duffle bag. Ratings of perceived exertion did not yield differences between the two bag types, but muscle activity indicated that a reduction in material at the top yielded lower muscle activity for all muscle groups investigated for sealing. Hence, subjective measures (perceived exertion ratings) were not as effective as objective measures (EMG) when measuring differences between the bags for the sealing methods tested. Differences between bags for sealing can be attributed to the increased physical demands associated with tightening the string, B-lock, cable tie, or wire tie around the additional material on the duffle bag.

Time taken to complete sealing was longer when tools were used and an increase in task time may increase overall exposure time. However, in an effort to reduce exposure to risk factors for WMSDs several mines were observed where job rotation was used; such as alternating between driving fork lifts and loading and sealing bulk bags. Hence, the overall increase in exposure over the day would be minimal.

Although there was no single sealing tool that was distinctly better based on physical demands, the pneumatic cable tie gun and the cable tie gun consistently produced lower muscle activity and perceived exertion ratings across muscles and body parts, respectively, as compared to the other sealing methods. In general, perceived exertion rating scores were lower when using a tool (cable tie gun, pneumatic cable tie gun, pull twist tool, screwdriver hook) as compared to not using a tool (string, drawstring, B-lock, manual cable tie) with the pneumatic cable tie gun having the lowest score of 0.9. Although the cable tie gun and pneumatic cable tie gun have lower EMG (percent RVE) values in general, the cable tie gun had higher muscle activity for the extensor and flexor muscles of the forearm in that the lever/trigger on the gun had to be manually pressed to advance and cut the cable ties. In comparison, the pneumatic cable tie gun trigger was only used to activate the pneumatics that would advance and cut the cable ties. The pneumatic cable tie gun had higher muscle activity for the anterior deltoid that could be attributed to the weight of the tool (780 g)–other tools weighed about half that of the pneumatic cable tie gun (cable tie gun (383 g), pull twist tool (405 g) and screwdriver hook (450 g)). Although the influence of using simple aids such as tool balancers was not tested, it might alleviate the higher anterior deltoid muscle activity associated with using heavier tools.

The novel tool designed to overcome the shortcoming of the pull twist tool—the screwdriver hook—did produce the intended effect, especially on muscle activity for the right (dominant) hand. Perceived exertion rating values, although not significant, were on average 0.3 points lower for the screwdriver hook. These findings are similar to those observed by Li (Li, 2002), where improved tool design that promoted more neutral postures reduced muscle activity values.

This study had several limitations. We were unable to recruit mine workers, who commonly close and seal bags and may have developed unique strategies to close and seal bags, to visit the laboratory for a multi-hour experiment; hence, a convenience sample from the general population was recruited. In addition, although our sample size is small, other studies that have tested similar tools have adopted a similar sample size (Li, 2002, 2003). Our sample was adequate to show significant differences between some closing and sealing methods; however, as the differences were small they should be interpreted with caution. Inferences for tool use cannot be made beyond the task tested here, although this work can provide some guidance on the benefits of using certain tools and methods. Efforts were made to include methods commonly observed when sealing bags; however there may be sealing methods that are not commonly used that were not included in this study. It may be possible to use different methods or bags not studied here to further reduce or eliminate exposure.

5. Conclusions

There is limited information on the physical demands associated with closing and sealing bulk bags. We evaluated the physical demands associated with two closing methods and eight sealing methods, using muscle activity, perceived exertion, subjective ratings of use, and time, to provide recommendations for methods to reduce exposure to risk factors for work-related musculoskeletal disorders. We identified that closing the spout bag using the flowering method posed the lowest physical demand. In addition, although the pneumatic cable tie gun took longer to use as compared to a few other sealing methods, it produced the lowest physical demands on average.

Acknowledgments

6. Disclaimer

The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH). Mention of any company or product does not constitute endorsement by NIOSH. We would like to thank Jonisha Pollard for her assistance developing the experimental protocols and reviewing of the final manuscript.

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Fig. 1.
Type of bags used; drawing of duffle (left), lab setup of duffle and spout, and drawing of spout (right).

Fig. 2.
Bag closing methods; snaking (left), flowering (right).

Fig. 3.
Bag sealing equipment.

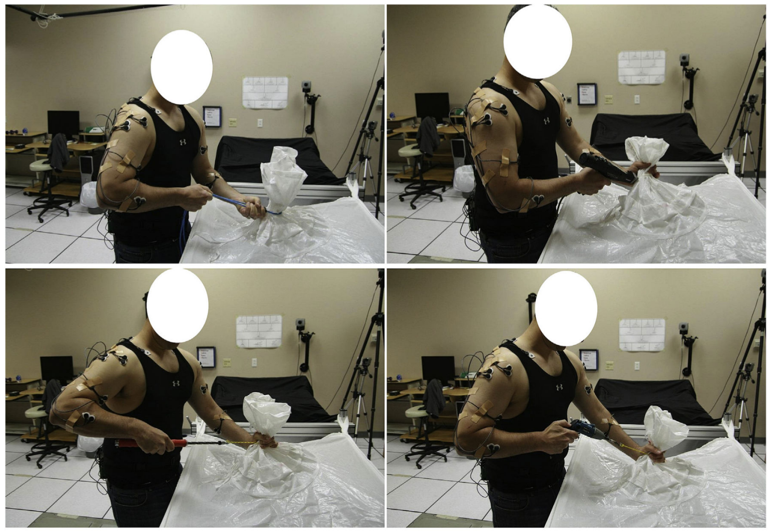

Fig. 4.
Example of participant sealing the spout bag with the B-lock (top left), pneumatic cable tie gun (top right), pull twist tool (bottom left), screwdriver hook (bottom right).

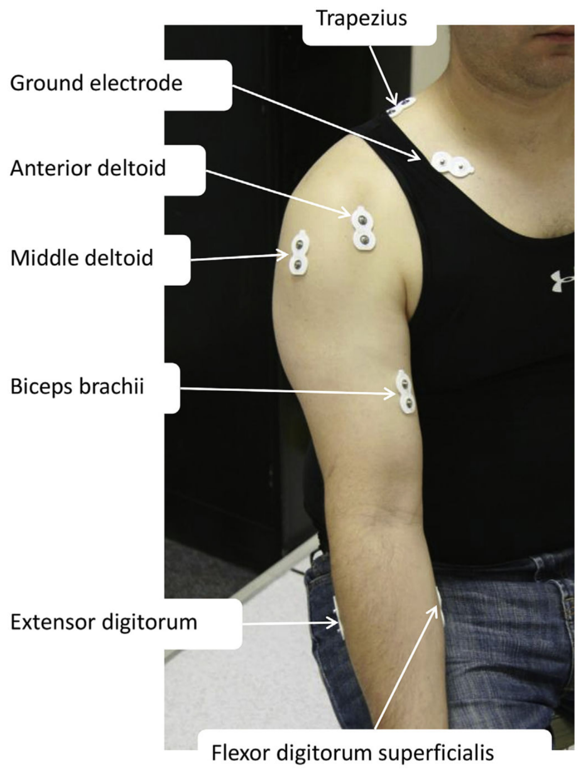

Fig. 5.
Location of EMG electrodes on right side of participant; similar locations were used for the left side.

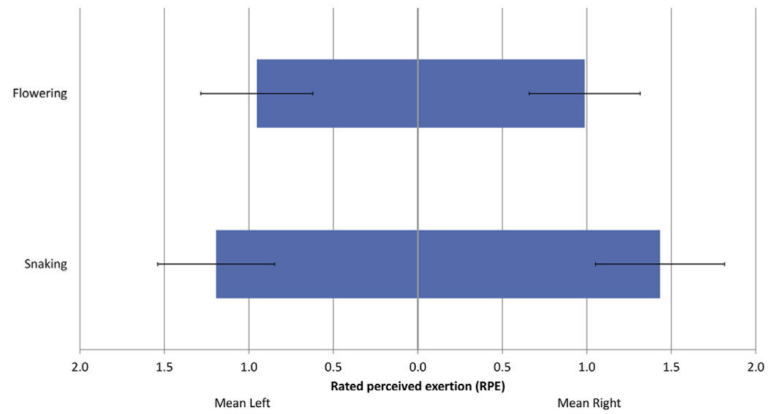

Fig. 6.

Mean perceived exertion ratings for the left and right sides of the body by closing method. (Error bars indicate the 95% confidence interval.)

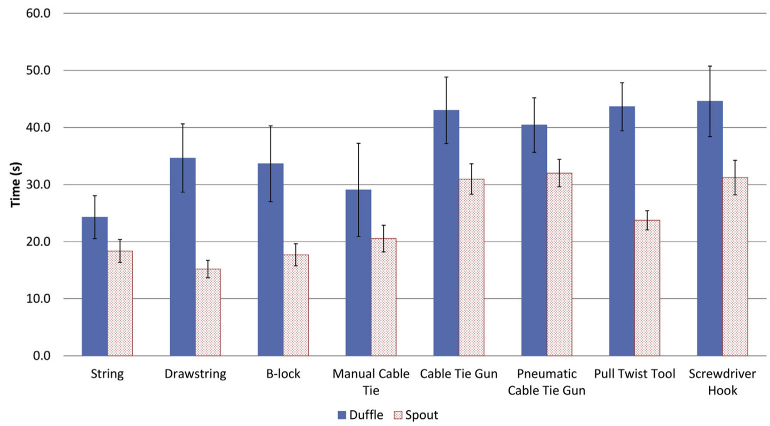

Fig. 7.

Time taken to seal the two types of bags using the eight closing methods. (Error bars indicate the 95% confidence interval.)

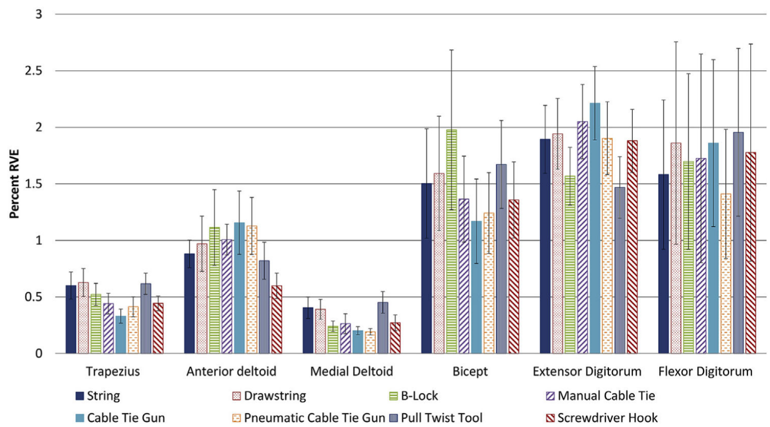

Fig. 8.

Muscle activity in percent RVE for the right (dominant) side for the eight closing methods (Error bars indicate the 95% confidence interval).

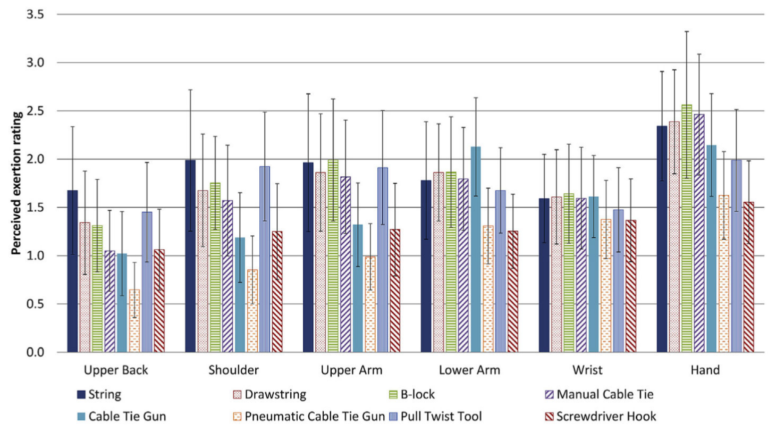

Fig. 9.

Perceived exertion ratings for the right (dominant) side for the eight closing methods (Error bars indicate the 95% confidence interval).

Table 1

Demographic information of participants.

		Males	Females	Overall
Age (years)	Mean (SD)	41.9 (8.6)	31.0 (4.8)	38.3 (9.1)
	Range	30–50	26–36	26–55
Height (cm)	Mean (SD)	177.8 (6.8)	168.3 (6.4)	175.6 (7.9)
	Range	168–185	165–178	165–185
Weight (kg)	Mean (SD)	81.9 (11.2)	61.9 (5.0)	75.2 (13.6)
	Range	63.6–99.9	56.8–68.1	56.8–99.9

Table 2

Mean, standard deviation (SD) for muscle activity in percent RVE for each muscle and post-hoc test statistics for closing method (F-statistic (F) and significance value (*p*)).

Muscle		Snaking method		Flowering method		Statistics	
		Mean	SD	Mean	SD	$F_{1, 11}$	p
Left	Trapezius	0.312	0.233	0.138	0.136	13.401	0.004 *
	Anterior deltoid	1.317	0.943	1.016	0.749	14.948	0.003 *
	Medial deltoid	0.280	0.149	0.177	0.094	23.601	0.001 *
	Biceps brachii	3.286	1.846	2.205	1.295	19.958	0.001 *
	Extensor digitorum	2.237	1.146	2.110	1.147	5.328	0.041 *
	Flexor digitorum superficialis	1.706	0.893	1.291	0.850	15.844	0.002 *
Right	Trapezius	0.320	0.237	0.132	0.131	11.328	0.006 *
	Anterior deltoid	1.578	0.988	1.335	0.901	12.033	0.005 *
	Medial deltoid	0.256	0.184	0.117	0.045	8.382	0.015 *
	Biceps brachii	2.868	2.919	1.910	1.851	8.025	0.016 *
	Extensor digitorum	2.535	1.05	2.071	0.795	15.253	0.002 *
	Flexor digitorum superficialis	2.476	2.041	1.828	1.587	15.506	0.002 *

* (indicates significant differences at $\alpha = 0.05$ adjusted with Bonferroni's correction).

Table 3

Repeated measures ANOVA results for muscle activity of individual muscles (F-statistic (F) with appropriate degrees of freedom for numerator and denominator ($F_{n, d}$) and significance value (p)).

Muscle		Bag type × Sealing method			Bag type			Sealing method		
		$F_{n, d}$	F	p	$F_{n, d}$	F	p	$F_{n, d}$	F	p
Left	Trapezius	$F_{7, 77}$	= 3.65	0.002*	$F_{1, 11}$	= 9.51	0.010*	$F_{3.32, 36.48}$	= 4.91	0.005*
	Anterior deltoid	$F_{3.03, 33.37}$	= 3.07	0.041	$F_{1, 11}$	= 5.37	0.041	$F_{2.34, 25.77}$	= 5.31	0.009*
	Medial deltoid	$F_{7, 77}$	= 3.28	0.004*	$F_{1, 11}$	= 25.23	0.000*	$F_{7, 77}$	= 12.61	0.000*
	Biceps brachii	$F_{7, 77}$	= 2.85	0.011	$F_{1, 11}$	= 1.54	0.24	$F_{7, 77}$	= 5.71	0.000*
	Extensor digitorum	$F_{7, 77}$	= 3.22	0.004*	$F_{1, 11}$	= 6.13	0.031	$F_{2.51, 27.63}$	= 5.55	0.006*
	Flexor digitorum superficialis	$F_{2.94, 32.33}$	= 1.91	0.149	$F_{1, 11}$	= 36.45	0.000*	$F_{3.08, 33.89}$	= 6.48	0.001*
Right	Trapezius	$F_{7, 77}$	= 1.77	0.105	$F_{1, 11}$	= 18.46	0.001*	$F_{7, 77}$	= 7.78	0.000*
	Anterior deltoid	$F_{2.62, 28.77}$	= 0.99	0.401	$F_{1, 11}$	= 3.06	0.108	$F_{2.2, 24.16}$	= 4.56	0.018
	Medial deltoid	$F_{7, 77}$	= 3.93	0.001*	$F_{1, 11}$	= 24.42	0.000*	$F_{7, 77}$	= 11.2	0.000*
	Biceps brachii	$F_{2.87, 31.6}$	= 2.18	0.112	$F_{1, 11}$	= 14.88	0.003*	$F_{2.04, 22.4}$	= 3.85	0.036
	Extensor digitorum	$F_{7, 77}$	= 3.59	0.002*	$F_{1, 11}$	= 23.05	0.001*	$F_{7, 77}$	= 15.07	0.000*
	Flexor digitorum superficialis	$F_{1.35, 14.82}$	= 1.8	0.202	$F_{1, 11}$	= 11.46	0.006*	$F_{1.79, 19.66}$	= 2.08	0.155

* (indicates significant differences at $\alpha = 0.01$)

Table 4

Repeated measures ANOVA results for perceived exertion ratings of individual body parts, mean right, mean left, and overall (F-statistic (F) with appropriate degrees of freedom for numerator and denominator ($F_{n, d}$) and significance value (p)).

Part of body		Bag type × Sealing method			Bag type			Sealing method		
		$F_{n, d}$	F	*p*	$F_{n, d}$	F	p	$F_{n, d}$	F	*p*
Left	Upper Back	$F_{7, 77}$	= 2.65	0.017	$F_{1, 11}$	= 2.01	0.184	$F_{1.86, 20.44}$	= 3.8	0.042
	Shoulder	$F_{3.52, 38.7}$	= 1.44	0.242	$F_{1, 11}$	= 1.13	0.311	$F_{2.06, 22.66}$	= 4.03	0.031
	Upper Arm	$F_{2.97, 32.68}$	= 2.18	0.11	$F_{1, 11}$	= 3.76	0.078	$F_{2.38, 26.16}$	= 5.94	0.005*
	Lower Arm	$F_{2.61, 28.68}$	= 2.22	0.115	$F_{1, 11}$	= 7.37	0.02	$F_{2.41, 26.51}$	= 5.14	0.009*
	Wrist	$F_{7, 77}$	= 2.22	0.042	$F_{1, 11}$	= 6.15	0.031	$F_{2.5, 27.45}$	= 5	0.010*
	Hand	$F_{3.01, 33.09}$	= 1.35	0.275	$F_{1, 11}$	= 6.09	0.031	$F_{2.79, 30.73}$	= 8.12	0.001*
Right	Upper Back	$F_{7, 77}$	= 2.57	0.02	$F_{1, 11}$	= 6.58	0.026	$F_{2.99, 32.92}$	= 3.2	0.036
	Shoulder	$F_{7, 77}$	= 2.46	0.025	$F_{1, 11}$	= 6.72	0.025	$F_{3.06, 33.64}$	= 3.73	0.02
	Upper Arm	$F_{2.82, 30.97}$	= 2.79	0.06	$F_{1, 11}$	= 5.24	0.043	$F_{7, 77}$	= 5.07	0.000*
	Lower Arm	$F_{3.25, 35.75}$	= 1.82	0.158	$F_{1, 11}$	= 6.82	0.024	$F_{7, 77}$	= 3.05	0.007*
	Wrist	$F_{3.19, 35.08}$	= 1.93	0.14	$F_{1, 11}$	= 10.06	0.009*	$F_{3.49, 38.35}$	= 0.51	0.706
	Hand	$F_{3.12, 34.31}$	= 1.21	0.323	$F_{1, 11}$	= 8.26	0.015	$F_{3.2, 35.24}$	= 3.8	0.017

* (indicates significant differences at $\alpha = 0.01$)