Field assessment of biomechanical and physiological demands in sand and limestone bagging operations

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Bagging operations are common in the mining industry and are associated with numerous musculoskeletal injuries. To better understand the physical demands of bagging operations, field evaluations quantifying low back loading and physiological costs of bagging tasks were performed at two bagging operations. A biomechanical model employing electromyography (EMG) and goniometry was used to estimate lumbar compression and a portable metabolic system used to assess heart rate and oxygen consumption. Manual palletizing of bags was found to generate a load of approximately 1,500 Newtons on the spine, with a few larger loads of 2,000-3,000 Newtons. The average oxygen cost for stacking was 5.3 METS, indicating moderately intense physical activity. Bag filling resulted in lower lumbar loads and a reduced physiological cost (3.2 METS), or a moderate level of energy expenditure. Use of a vacuum hoist resulted in a 39% reduction in the peak compressive load on the worker's spine compared to manual lifting when palletizing 75-lb bags.

Introduction

Many mining commodities are packaged and shipped using bags. These may be small bags (typically having capacities ranging from 40 to 100 pounds) or bulk bags (or totes) having capacities ranging from 2,000 to 3,500 pounds. Small bags are usually loaded onto pallets for transport, while bulk bags (or Flexible Intermediate Bulk Containers [FIBC]) are usually moved around within a facility via forklift or crane and are typically transported by rail on a boxcar. Both types of bags require a significant amount of manual handling by workers and both have been associated with the development of musculoskeletal disorders (MSDs).

While the loading of small bags onto pallets has been totally automated in some loading facilities, there are many instances where the job of loading small bags onto pallets is still being performed manually. Repetitive handling of small bags and stacking them on a pallet is associated with the development of low back disorders (47% of bagging injuries). This is particularly true if the workplace layout is poorly designed and/or appropriate lifting aids (such as lift tables) are not provided. Some small bag designs are prone to leaks and breakage (especially if moisture comes in contact) and a significant amount of product wastage can be experienced.

In addition to manual stacking of bags on pallets, bag filling workstations are another source of ergonomic concern in bagging operations. Small bags may be filled in a variety of ways, but the predominant method is for a bagger to be seated in front of a bank of two to four horizontally oriented fill spouts, where he or she must continuously retrieve paper bags from a stack of empties, place the end of the bag onto one of the fill spouts, and activate a switch to initiate the bag filling process. Well more than a dozen bags per minute can be filled at these workstations. Injuries for bag fillers tend to involve the fingers (50%) and hand (10%). In some plants, the worker stands while filling bags. Standing workstations are typically associated with a vertically oriented fill spout that the worker holds the bag under during the filling process. Bags filled in this manner are often manually fed into a machine that sews or heat seals the bag closed.

Due to the physical demands of bagging operations, and the prevalence of bagging operations in mining, the National Institute for Occupational Safety and Health (NIOSH) is currently developing an audit tool for bagging operations. As part of this effort, numerous field visits have been conducted to assess the demands of various bagging tasks. These efforts have involved collection of EMG and goniometer data on bag palletizing and filling operations, as well as collection of physiological data (oxygen consumption and heart rate) associated with the performance of bagging tasks.

Practice Innovation

The data presented are from 6 subjects at two bagging operations that agreed to participate in a field data collection involving collection of EMG, goniometric, and metabolic data.

Biomechanical Model

A biomechanical model developed by Dolan and Adams (1993) was employed to estimate compressive loads on the spine during performance of bagging tasks considered to be the most physically demanding. This model used surface EMG data collected from the erectors spinae at the L3 and T10 levels. A series of six reference contractions were used to determine the effects of muscle length and spine curvature on the extensor moment in different postures, and a correction factor was employed for the effect of contraction velocity. For reference contractions, subjects pulled vertically on a handle attached to a load cell at various angles of trunk flexion. These pulls involved a slow ramping up of force in each posture so that the EMG-moment relationship could be determined throughout a range of moments in each posture. Compressive forces on the lumbar spine were calculated from estimated extensor moments.

Metabolic Cost

Tasks observed to involve significant energy expenditure (e.g., palletizing) were assessed using a portable metabolic monitor (COSMED Inc.), comprised of a measurement unit worn by the subject to which a face piece is connected via hoses. The metabolic monitor was calibrated for both volume and gas concentration using procedures established by the manufacturer, and the monitoring system was placed on the subject. Oxygen consumption and heart rate during bagging tasks (also collected via metabolic monitor) was used to assess workload demands and physiological fatigue. Upon donning the unit, subjects were asked to perform their normal tasks while the metabolic data were collected onboard the metabolic monitor.

Findings

Biomechanical results

Palletizing at a midwestern sand operation

One midwestern plant visited bagged industrial quartz in 75-lb bags. This plant used a single bagging line with one bagger who performed all bagging tasks, from filling to palletizing. Due to the weight of the bags, the company bought a vacuum hoist to assist with the palletizing tasks. This plant served as a good location to compare the biomechanical loading associated with using the vacuum hoist as compared with manual bag stacking. Figure 1a and 1b illustrates the worker performing the palletizing task using the vacuum hoist and manual lifting, respectively. Figure 2a and 2b presents the estimated lumbar compression data from manual stacking and stacking via the vacuum hoist, respectively.

Figure 1. Worker palletizing 75-lb bags using (a) vacuum hoist and (b) manual lift.

Results of this comparison indicate that manual stacking resulted in an average peak compressive force of 2,335 N (± 554). Use of the vacuum hoist resulted in a 1,426 N (± 409) peak compressive force (on average). Thus, the use of the vacuum hoist reduced the compressive load on the spine of 39%, on average.

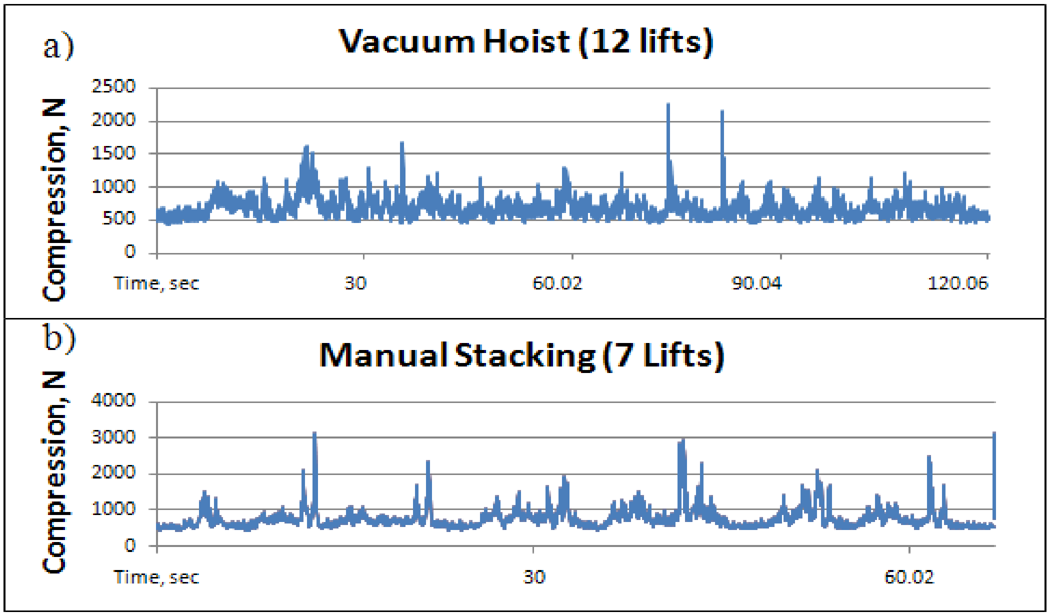


Figure 2. Estimates of lumbar compressive forces: (a) using vacuum hoist, (b) manual stacking on pallets.

Palletizing at East Coast Limestone plant

Data from an East Coast plant bagging a treated pulverized limestone were also collected and examined in relation to spinal loading. Bags in this plant were a self-sealing variety, but instead of the usual paper, these bags were made of plastic. The bags were somewhat flimsy compared to paper bags and did not stack as neatly. As a result, it was necessary to surround the pallet with a cardboard box to contain the bags and provide structural stability to the pallet. Figure 3 illustrates the stacking station at this particular line of the plant.

Table 1 presents estimates of lumbar compression for two workers loading a full pallet of bags at this plant. Forty bags defined a full pallet (5 bags per layer and 8 layers per pallet). However, workers occasionally had to throw bags that were off-weight (determined via automatic in-line scale with audible alarm) into a "waste bin," which increased the number of lifts required. During the entire shift, a total of 42 boxes (pallets) were typically loaded. Thus, a total of 1,680 bags had to be loaded on pallets per shift by the worker, for a total of 42 tons of material that were manually handled (not counting off-weight bags).

Bag Filling

A bagger at the East Cost limestone plant was evaluated in terms of the low back loading associated with his job. Results are shown in Figure 4. This plot shows data collected for a little over a half hour while the bagging tasks were performed.

Figure 3. Stacking operations at East Coast limestone plant.

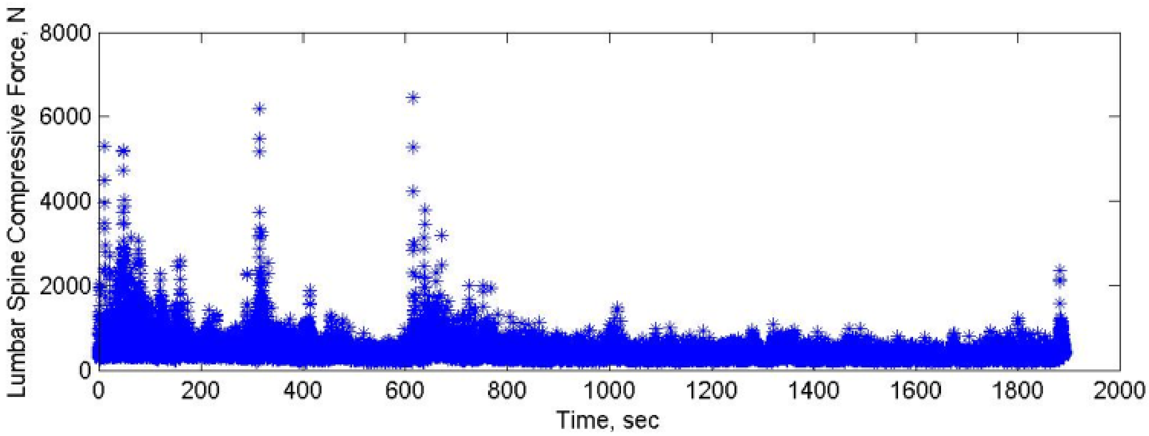


Figure 4. Lumbar spine compression estimates for bagger over 30+ minute period.

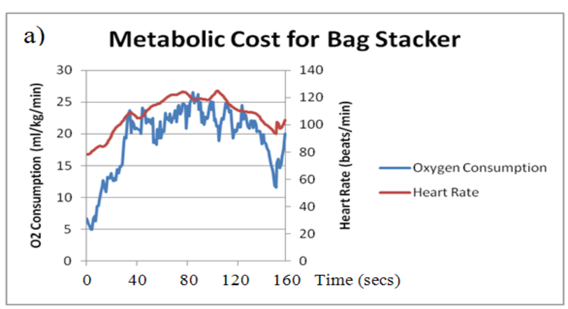
Table 1. Estimated peak spine compression (N) during bag lifting at East Coast plant

	# lifts performed	Average peak spine compression, N (± SD)	Minimum spine compression, N	Maximum spine compression, N
Stacker #1	45	1665 (± 461)	1121	2966
Stacker #2	42	1279 (± 309)	581	2165

One can see a few periods where the instantaneous spinal load becomes quite high; however, in general the loads associated with this task were associated with peak compressive forces generally lower than 1 kN (see especially after the 800-second mark). The periods of higher activity were associated with the worker retrieving bags at the start of the bagging run and, occasionally, while standing up on his seat and banging on the chute with a rubber mallet to loosen material stuck in the chute when the material in the chute ran low.

Metabolic data

Heart rate and oxygen consumption cost data were collected during the stacking of a pallet to determine the physiological load experienced by both stackers and baggers. Figure 5 provides oxygen consumption and heart rate data for a stacker for one pallet's worth of bags and a bagger performing continuous bagging operations. The average metabolic (oxygen) cost for stacking was 5.3 METS (1 MET = 3.5 ml/kg/min, a resting metabolic rate), which is considered to be moderately intense physical activity. Bag filling



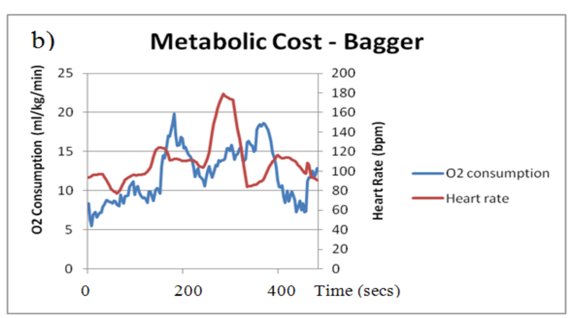


Figure 5. Metabolic data from: a) stacker and b) bagger.

resulted in generally lower lumbar loads and a reduced physiological cost (3.2 METS), or a moderate level of energy expenditure.

Discussion

Plants have numerous options for loading materials in bags. With the advent of better and cheaper robots, bagging operations are increasingly becoming automated; however, it is still common to find operations that perform all bagging tasks manually. Some plants, such as the East Coast plant visited in this study, have a combination of automated and manual procedures. At this plant, the flimsy nature of the bag used for a specialty product was not amenable to the use of robots and therefore had to be stacked by hand.

The midwestern plant visited was an atypical operation in that there was a sole bagging operator who performed all of the bagging tasks in the plant. He would fill twelve bags (enough to completely fill the short stretch of conveyor present) then walk around from the bagging station and advance the conveyor bag by bag, using the vacuum hoist to lift the 75-lb bags to the pallets. This particular situation was well-suited to the use of a mechanical assist for palletizing due to the self-paced aspect of the bagging process. Other plants find the use of assists such as vacuum hoists to be slow or cumbersome, especially for bags weighing 50 lb or less. Some plants do mandate the use of assists for heavier bags (especially 75- or 100-lb bags). Data collected in this study suggest a substantial benefit to the use of a vacuum hoist, as the peak compressive loading during its use was 39% lower than when manual lifting/stacking was performed.

Biomechanical model estimates obtained at the East Coast bagging facility were indicative of moderate to high spinal loads during manual palletizing operations. The design of the palletizing tasks included some favorable characteristics, especially because a waist-height conveyor was used and there was generally little need for control of the load at the end of the lift. The cardboard box required to provide stability for the unit load, however, did present a complication that served to increase the lifting moment in some circumstances.

While the compressive loading on the spine was not tremendously excessive, the frequency of lifting could certainly lead to fatigue failure of spine tissues (e.g., vertebral endplates) even at these levels of spinal compression. As mentioned previously, a total of 1680 bags had to be loaded on pallets per shift by the stackers, for a total of 42 tons of material that were manually handled during the shift.

The data collected in these continuing field studies will be used to support the development of an ergonomics audit tool for bagging. Field study data provide objective evidence of the risks of physiological and biomechanical demands, and can be used to inform audit tool recommendations. The goal of the audit tool is to provide a method for evaluating any bagging operation, and provide feedback to users about methods of improving the design of their system.

Reference

Dolan, P., Adams, M.A. (1993). The relationship between EMG activity and extensor moment generation in the erectors spinae muscles during bending and lifting activities. *J Biomech*, *26,* 513-522.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational safety and Health.