Applied Ergonomics 41 (2010) 822–831

Contents lists available at ScienceDirect

Applied Ergonomics

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

Investigating reduced bag weight as an effective risk mediator for mason tenders☆

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ARTICLE INFO

Article history:
Received 31 December 2008
Accepted 5 February 2010

Keywords:
Spine load
Productivity
Low back injuries

ABSTRACT

Masonry workers face some of the highest physical demands in the construction industry where large bags of masonry material weighing 42.7 kg are commonly handled by mason tenders who mix the mortar, distribute mortar and bricks/blocks, and erect/dismantle scaffolding throughout the day. The objective of this study was to determine the effectiveness of using half-weight bags (21.4 kg) on reducing the biomechanical loading, physiological response, and perceived exertions. Ten male subjects performed asymmetric lifting tasks simulating unloading bags from a pallet. Muscle activity, trunk kinematics, heart rate, blood pressure and subjective rating data were collected. Spine loads were predicted from a well-validated EMG-assisted model. Bag weight, lift type, bag height at origin, and asymmetry at destination significantly impacted the spine loads. While there was a 50% reduction in bag weight, the peak loads for the half-weight bags were only 25% less than the more available full-weight bags (a reduction of about 320 N of shear and 1000 N of compression). Lifts allowing movement of the feet reduced the loads by about 22% in shear and 27% in compression compared to constrained postures. Interestingly, cumulative spine loads were greater for the lighter bags than the heavy bags (∼40%). The subjective ratings of exertion and risk were significantly lower for the lighter bags.

Relevance to Industry: The reduction in peak spine loading for the half-weight bags, particularly at the higher heights and when the feet were allowed to move could significantly reduce the injuries of masonry workers. However, there were trade-offs with cumulative loads that may minimize the reduced risk. Overall, given the limited amount of time lifting bags, the reduction of peak loads

1. Introduction

According to the Bureau of Labor Statistics (BLS), the construction industry consistently reports some of the highest injury rates in private industry(United States Department of Labor, 2005). In a study by Meerding et al. (2005), 59% of construction workers had musculoskeletal complaints in the preceding 6 months, and 21% during the previous day. Forty-one percent had low back complaints in the preceding 6 months, with 16% of low back complaints requiring sick leave (Meerding et al., 2005). Thus, the general construction industry has some of the highest rates of work-related musculoskeletal disorders (WMSDs). Further, many of the well-known risk factors for the development of WMSDs such as heavy loads, awkward postures, and repetitive lifting are common occurrences (Bernard, 1997; Hoogendoorn et al., 1999; Marras et al., 1995, 1993). The presence and the magnitude of these risk factors results from the diverse nature of jobs in the construction industry—operating heavy equipment, forming walls, laying block, framing walls, hanging drywall, and so forth.

Masonry workers' tasks are diverse in nature and physical demand. Brick and block masons handle bricks, concrete blocks and similar building materials to build external and internal walls. This work is typically done on scaffolding. Mason tenders mix the brick/block mortar, distribute mortar and bricks/blocks to masons, and erect/dismantle scaffolding. Both groups are exposed to many physical risk factors for WMSDs (Goldsheyder et al., 2002). Goldsheyder and colleagues found that mason tenders reported a higher prevalence of musculoskeletal complaints (82% in previous 12 months) and low back pain (65%) than all construction workers, while 12% reported missing work as a result of their complaint (Spielholz et al., 2006). In a study of masonry workers on non-residential job sites, the Construction Safety Association of Ontario found that workers may bend forward more then 1000 times per

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doi:10.1016/j.apergo.2010.02.001

shift, accompanied by lifts above shoulder height and awkward and constrained postures (Marks, 1999). In addition, these types of workers oftentimes are exposed to loads that are extreme and approach strength limits. Concrete and cement blocks can weigh up to 20 kg with bags of mortar weighing up to 50 kg. Vi and associates (Vi, 2007) reported that eleven mason tender activities observed on commercial and residential building sites resulted in average low back (L4–L5) peak compression forces exceeding 3400 N. Average low back compression forces lifting Portland cement bags to mix mortar and concrete blocks averaged approximately 5400 N (Vi, 2007) When considering that up to several hundred blocks can be laid by a worker each shift which requires many bags of mortar and other masonry material to be handled, the potential for both development of a musculoskeletal disorder, particularly low back disorders, is high in this industry sector. Thus, many of the typical tasks for a masonry worker require high repetition of lifting heavy weights.

Portland cement bags used to mix mortar in the United States typically weigh 42.7 kg. A survey of local construction companies revealed that mortar bags commonly delivered to jobs sites weigh 42.7 kg, nearly double the load constant (23.2 kg) in the NIOSH Lifting Equation, which is the best case recommended maximum weight of lift (Waters et al., 1993). One study surveyed Portland cement manufacturers, distributors and users in four large U.S. metropolitan areas to determine the relative use of heavy (42.7 kg) bags and half-weight (21.4 kg) bags. Only 5 manufacturers ($n = 14$) produced the half-weight bags and none of the distributors ($n = 26$) reported including half-weight bags in their inventory (Salem et al., 2008). These heavy (42.7 kg) bags are large and bulky, making lifting the weight even more difficult. Recently, mortar bags have become available in 21.4 kg bags as recommended as best practices (Entzel et al., 2007). This led to the objective of the study – determine the biomechanical and perceptual exertion trade-off between transferring full-weight (large—42.7 kg) and half-weight (small—21.4 kg) bags of cement during simulated asymmetric lifting.

2. Methods

2.1. Study overview

The study adopted a repeated measures experimental design that evaluated the biomechanical and perceived differences when lifting equal total weights of 21.4 kg and 42.7 kg bags of masonry material. Male subjects, experienced in masonry work, performed asymmetric lifting tasks simulating unloading bags of masonry material from a pallet.

2.2. Subjects

Subjects who were experienced in masonry work were recruited from construction companies located in Southwest Ohio. Construction companies were randomly chosen from an online phone directory and were contacted by one of the investigators from the University of Cincinnati's Low Back Biomechanics and Workplace Stress Laboratory. An investigator sent study related material to the point of contact which was distributed to employees with their paycheck envelopes. When an interested individual contacted the lab, an investigator asked the individual a series of questions from a Medical Screening Questionnaire to determine the individual's level of health and fitness and eligibility to complete the study. If the subject met the eligibility criteria, a mutually agreeable time was scheduled to come to the lab and complete the study. Ten male subjects were recruited with an average (standard deviation) age of 34.8 (9.1) years, height of 184.1 (4.4) cm, weight of 99.8 (18.3) kg, and experience working in the industry of 9.6 (5.9) years.

2.3. Study design

The test set-up was designed to simulate unloading bags of mortar from a pallet and placing them at the level of a portable cement mixer. The bags of mortar were stacked in two different configurations, depending on the weight of the bag, on a wooden pallet located directly in front of the subject. The bags of mortar were stacked on the edge of the pallet five high for the 42.7 kg bags and in two stacks of 5 placed next to each other for the 21.4 kg bags. Two destination shelves, set to a height of 90 cm, were located 90^{o} clockwise (CW) and counterclockwise (CCW) to the stacked bags (Fig. 1A and B). A force plate was positioned against the front of the pallet.

The independent variables were the mortar bag weights (21.4 kg or 42.7 kg), position of the bags (top row, 2nd, 3rd, 4th, bottom), destination asymmetry of the lift (left or right), and type of lift (confined space or free moving of feet). The five positions of the bags were 6 cm, 16 cm, 28 cm, 39 cm, and 50 cm from the floor

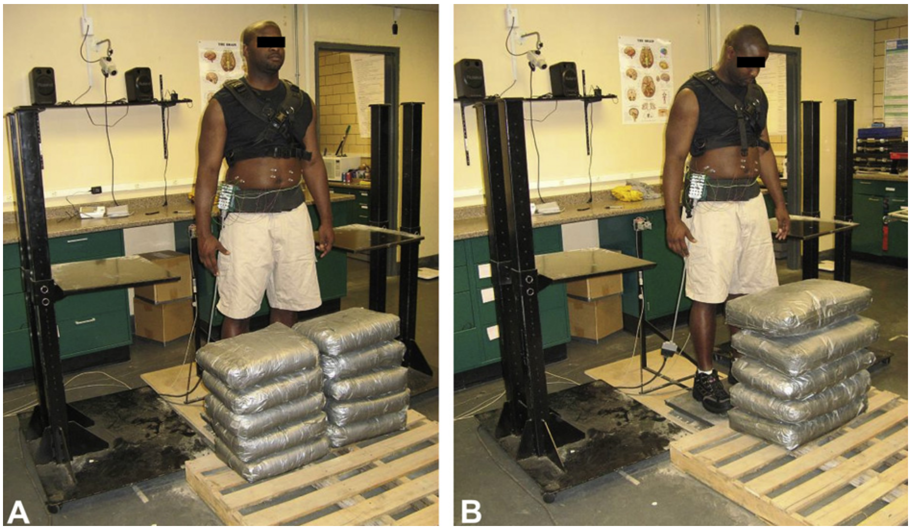

Fig. 1. Test set-up for 10 bags weighing 21.4 kg (A), and 5 bags weighing 42.7 kg bags (B).

to the middle of each bag. The two types of lifts were confined space where the subject was instructed to keep his feet planted on the force plate during the lifts, simulating being in small space which didn't allow much movement, and the free moving conditions where the subject was allowed to move his feet freely, simulating an unconstrained work area with free-style lifting. No additional directions were provided on the lift style (e.g. bent knees vs. stoop lifting).

The dependent variables consisted of spinal loading at L_5/S_1, trunk moments at L_5/S_1, heart rate, blood pressure, Borg's Rating of Perceived Exertion (RPE), and a Task Risk Rating (TRR). The spine loads and trunk moments were predicted by a well-validated EMG-assisted model that was developed over the last 23 years at the Biodynamics Laboratory at The Ohio State University. The model has been validated in lifting of material and published in many peer-reviewed journals (Marras and Reilly, 1988; Reilly and Marras, 1989; Marras and Sommerich, 1991a, 1991b; Granata and Marras, 1993, 1995a, 1995b; Marras and Granata, 1995; Marras and Granata, 1997; Davis et al., 1998). Several inputs are generated and integrated into the model in order to predict the loads and trunk moments including: body anthropometry – height, weight, trunk depth, and trunk breadth, three-dimensional trunk kinematics as measured by the lumbar motion monitor (LMM) (Marras et al., 1992), muscle activity of 10 trunk muscles as measured by electromyography (EMG) (Mirka and Marras, 1993), three-dimensional kinetics as measured by a force plate and goniometry system. The LMM, which is essentially an exoskeleton of the spine that is worn on the back using a shoulder harness and waist belt, measures three-dimensional trunk position, velocity, and acceleration (Marras et al., 1992). Muscle activity was measured for the right and left pairs of the erector spinae, rectus abdominius, internal obliques, external obliques, and latissimus dorsi using Ag–AgCl surface mounted electrodes. The kinetics including forces and moments during the closed loop conditions when the feet were stationary were measured by the force plate (Bertec 4060) and then translated and rotated up to L5/S1 through mathematical equations utilizing the goniometric data. The technique for measuring the forces and moments has been previous been reported by Fathallah and associates (Fathallah et al., 1998). All the data is input continuously into a spine load model to predict the instantaneous three-dimensional spine loads.

Heart rate and blood pressure were measured immediately after each specific lift condition (e.g. set of lifts at a given weight) while the subject was standing using an Omron blood pressure monitor (Model HEM-711) positioned on the subject's arm which was placed at the side of the body. Similarly, subjective data was also gathered immediately after each specific lift condition using Borg's Rating of Perceived Exertion and a Task Risk Rating. The RPE rating inquires about the perception of the exertion level on a 6–20 scale (from no exertion to maximal exertion) (Borg, 1982). The TRR index is a new simple metric that determines the perception of risk of injury by asking “If you were to perform this task on a daily basis, how likely is it that you would be injured?” and was on a scale of 1 (not at all likely) to 10 (extremely likely).

2.4. Task description

Each subject lifted a total of 20 large bags (42.7 kg) and 40 small bags (21.4 kg) from a sagittal symmetric origin to an asymmetric destination (right or left 90°). The lifts were blocked into lifting conditions that were randomized for each subject. A lifting condition corresponded to the combination of weight of the bag (small – 21.4 kg vs. large – 42.7 kg) and lift type (confined space vs. free moving). During half of the lifting conditions, the subjects were required to keep their feet stationary on the force plate (e.g. a confined space lift) while during the second set of lifting conditions participants were allowed to move their feet freely (e.g. free moving lift). Within each of these conditions, bags were lifted from a sagittally symmetric position from each of the five rows (top to bottom) to the asymmetric shelves (alternating left or right). For each condition, either 10 small bags or 5 large bags were lifted and were repeated to ensure all bags on each row were lifted to both shelves. Thus, 20 small bags and 10 large bags were lifted under the confined space and free moving lifting conditions. For all lifts, individuals were instructed to use any lifting technique (e.g. stoop, squat, grip of bags) desired but to keep the technique the same throughout all the lifting trials.

2.5. Procedure

Upon arriving at the Low Back Biomechanics and Workplace Stress Laboratory, the individual was asked to read and sign an Informed Consent Statement approved by the University of Cincinnati's Institutional Review Board (#05-10-25-06-EE). Full anthropometric data was then collected and the subject was prepped for EMG using standard application procedures (Marras and Granata, 1995). The subject was then placed in a stationary reference frame where maximum voluntary contraction (MVC) data was collected and was utilized to normalize the subsequent EMG data during the trials (Marras and Granata, 1995; Mirka and Marras, 1993). The LMM was then fitted to the subject and the subject was positioned on a force plate (Fig. 1) where a goniometric system (moment arm monitor and pelvic angle monitor) was also attached. One of the investigators then took baseline heart rate and blood pressure readings on the subject. The investigator also explained Borg's Rating of Perceived Exertion (RPE) and the Task Risk Rating (TRR) and the lifting protocol. Data collection then proceeded with heart rate, blood pressure, and RPE and TRR data being collected after the completion of each condition. The subject was given a break in between trials to minimize fatigue. The timed breaks were at least 5 min long where the subject stood off the force plate while the next condition was set-up.

2.6. Data analysis

Both peak and cumulative spine loads (three-dimensional) at L_5/S_1 were calculated using the EMG-assisted model along with the three-dimensional trunk moments for a given lift. The cumulative loads were first computed for each lift as the summation of the instantaneous load (in each dimension) from origin to destination. Cumulative load for each lifting condition (all lifts for the combination of lift type and bag weight) was computed by integrating the loads for the continuous load curve using a rectangular estimation fit with 0.01 s slices. While each individual lift was evaluated for cumulative loads, the lifting phase (e.g. box in the hand) was evaluated due to how the data was collected. This estimation under-estimated the overall cumulative load, with a further discussion being found in the limitations. Peak values of the kinematics, kinetics, and muscle activity were also analyzed for additional discussion into the nuances between the bag conditions (see Discussion for further details).

The impact on productivity and cost was calculated by taking into account material cost of the bags of mortar, time to perform the lifts, and wage of the worker. Calculations estimated the total cost for the small and large bags for a specific amount of material lifted.

2.7. Statistical analysis

Descriptive statistics (mean and standard deviations) were calculated for the dependent variables as a function of the independent variables. A repeated measure, split-plot analysis of variance was utilized to identify significant effects with one model for each dependent variable. SAS statistical analyses software was utilized to compute the within subjects ANOVA using PROC GLM procedures. Standardized Tukey post-hoc tests were utilized to determine the sources of significant effects.

3. Results

3.1. Peak trunk moment and spine loading parameters

Table 1 provides a summary of the Analysis of Variance (ANOVA) results for the trunk moments and spine loads. In general, the majority of the main effects of bag weight (21.4 kg vs. 42.7 kg), lift type (constrained posture vs. free moving), row (height of bag at origin), and asymmetry at destination (right vs. left) were all found to have significant impact on the three-dimensional trunk moments and spine loads. There were only two significant interactions, which were for lift type by asymmetry for lateral trunk moment and lateral shear force.

Overall, the 42.7 kg bags increased the anterior–posterior (A–P) shear and compression loads by approximately 320 N and 1000 N, respectively as compared to the 21.4 kg bags (see Fig. 2). Basically, there was a significant decrease in loading for the lighter bag that were ½ the weight of the large bags but it was not equivalent to ½ the spine loading in A–P shear and compression. A consistent trend was also found for trunk moment as a function of bag weight where the large bags increased trunk moment by 22.5% for sagittal moment and approximately 25% for lateral and axial moment.

The direction of where the bags were lifted impacted the lateral shear loading where lifting to the right had higher loads than lifting to the left (about 180 N or 30%). A similar trend was also seen for the trunk moments where lifting to the right had higher lateral (about 20 N or 13%) and axial (about 38 N or 21%) than lifting to the left.

The height at the origin was found to influence significantly the three-dimensional loads (Fig. 3). While obviously the highest loads were for the large bags when lifted at the low height positions (e.g. bottom – 5 cm high and 2nd from bottom – 16 cm high), the impact of height was universal across the size of bags. The greatest loads were seen at the bottom – placed on top of the pallet with the lowest loads at the top (about 50 cm from floor to middle of bag) and second from the top (about 39 cm from floor to middle of bag). The lower levels as compared to the top two levels increase lateral shear by 29%–50%, A–P shear by 23%–50%, and compression by 30%–63%. Basically, the lower levels significantly increased the three-dimensional loads to levels that would pose significant risk of low back injuries. As expected, the trunk moments have a very similar trend with the highest three-dimensional trunk moments for the two lowest origin heights and the lowest moments were in the upper two height positions (sagittal – 33% to 55% higher for lower levels, lateral—40% to 67% higher for lower levels, and axial—29% to 50% higher for lower levels).

One of the more interesting results was the significant decrease in thee-dimensional loading when the mason handlers were able to move their feet during the lifting of the bags (e.g. free moving compared to constrained posture), about 22% in shear forces and 27% in compression force (see Fig. 4). This translated into about 75 N in lateral shear, 350 N in A–P shear, and 1400 N in compression. The main difference in lateral shear between confined lifting and free moving was when lifting to the right. Similar differences were found for the three-dimensional trunk moments (about 20% lower in all three planes for the free moving lifts).

3.2. Cumulative spine loading Parameters

The cumulative loads provided a slightly different picture of the impact of bag weight. As seen in Fig. 5, the lighter bags produced more cumulative loads in all three planes. The estimates evaluated lifting the same amount of weight for both bag conditions (e.g. 2 small bags for every large bags). This translates into about 40% more cumulative three-dimensional spine loads for the 21.4 kg bags as compared to the 42.7 kg. One of the main factors that impacted the cumulative load was whether the lifts were performed under constrained conditions as compared to free moving of the feet (Fig. 6). Lifting the light bags (21.4 kg) under the confined space condition produce the largest cumulative loads (all three planes) while lifting the light bags allowing the feet to move had cumulative loads similar to those of the heavy bag (42.7 kg) under confined space conditions. Surprisingly, the heavy bag under the free moving lift conditions produced the lowest cumulative loads, mostly due to the lower number of lifts as compared to the small bags.

3.3. Perception and physiological responses

Overall, the participants rated their perceived exertion (RPE) during the lifting of small bags as being significantly lower than that of the large bags ($p < 0.0001$). The RPE was 9.4 for the small bags and 13.0 for the large bags (a difference of 3.6 for a 6–20 scale), indicating a large impact on the perceived exertion by reduced weight. This difference represented a 28% reduction in perceived exertion. Similarly, the perceived risk of injury (TRR) for the small bags was significantly lower than the large bags ($p < 0.0001$). The difference in TRR between the small and large

Table 1
Statistical summary of the Analysis of Variance for trunk moments and spine loads (Bolded values indicate significant *p*-values at 0.05 significance level).

	Sagittal trunk moment	Lateral trunk moment	Axial trunk moment	Lateral shear load	Anterior–posterior shear load	Compression
WEIGHT (WGHT)	**<.0001**	**<.0001**	**0.0004**	0.11	**0.001**	**<.0001**
LIFT TYPE (LIFT)	**<.0001**	**0.002**	**0.003**	**0.003**	**0.001**	**<.0001**
ROW	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
ASYMMETRY (ASYM)	0.24	**0.02**	**0.002**	**<.0001**	0.22	0.29
WGHT × ASYM	0.76	0.32	0.24	0.41	0.57	0.60
LIFT × ASYM	0.68	**0.02**	0.07	**0.002**	0.33	0.53
ASYM × ROW	0.71	0.96	0.92	0.18	0.56	0.62
WGHT × ROW	0.25	0.49	0.71	0.78	0.32	0.33
WGHT × LIFT	0.69	0.49	0.84	0.93	0.77	0.72
LIFT × ROW	0.81	0.69	0.53	0.94	0.72	0.75
WGHT × ASYM × ROW	0.68	0.75	0.71	0.82	0.43	0.47
WGHT × LIFT × ROW	0.82	0.72	0.47	0.65	0.67	0.80
WGHT × LIFT × ASYM	0.38	0.29	0.32	0.87	0.28	0.39
LIFT × ASYM × ROW	0.94	0.88	0.94	0.89	0.94	0.95
WGHT × LIFT × ASYM × ROW	0.76	0.69	0.59	0.38	0.57	0.66

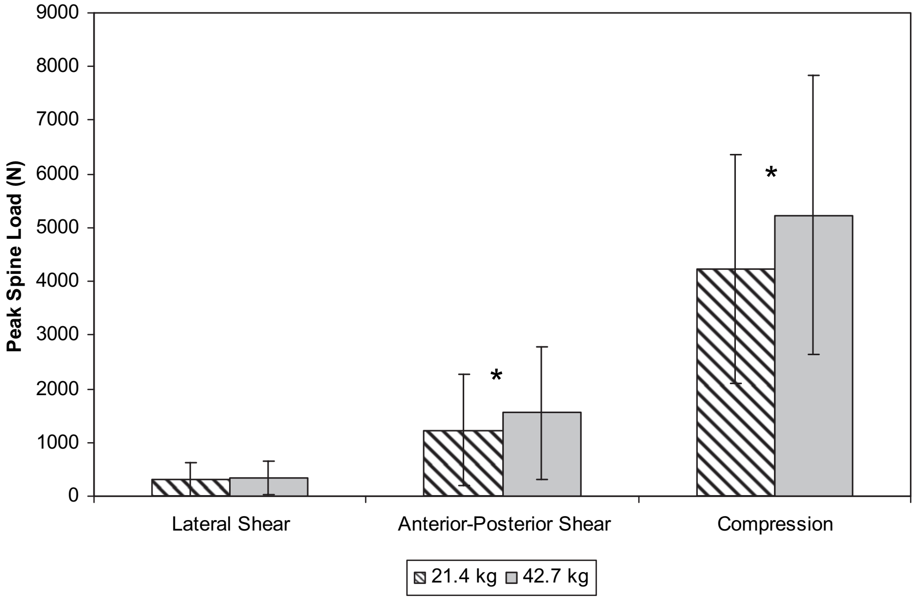

Fig. 2. Peak three-dimensional spine loads as a function of bag weight. (* indicates a significant difference between 21.4 kg and 42.7 kg bags). Error bars are standard deviations.

bags was 2.8 (small at 3.1 and large at 5.9 on scale 1–10), a 48% difference. Again, this difference represents a major shift in the perceptions of the mason tenders when lifting the small bags. Finally, there was no difference between the small and large bags (either as a main effect of interaction) for the physiological responses—heart rate and blood pressure ($p > 0.08$).

4. Discussion

Lifting bags of masonry material such as cement, mortar, and sand is an extremely physically demanding job. The results of the current study provide further support that lifting heavy loads produce large loads on the spine during lifting, especially when lifting close to the ground or with the large traditional bags. Based on the peak spine loads, the A–P shear and compression spine loads were reduced by 25% for the small bags. While the weight was reduced by half for the small bags, the loads were not cut in half as compared to the large traditional bags. Although our data does not allow a breakdown of the contribution of the load and trunk, one potential explanation for a smaller reduction in loading (e.g. less than 50% reduction for smaller bags) was the fact that the load of the bag was only one contributing factor with the load due to the trunk of the person plays a significant role in the resulting loads. The body weight lifted is large and relatively unchanged as compared the change in bag weight between the large and small bags. Some evidence that indirectly supports this notion was that the dynamic trunk moments had almost an identical trend to the spine loads indicating that the participants altered how they

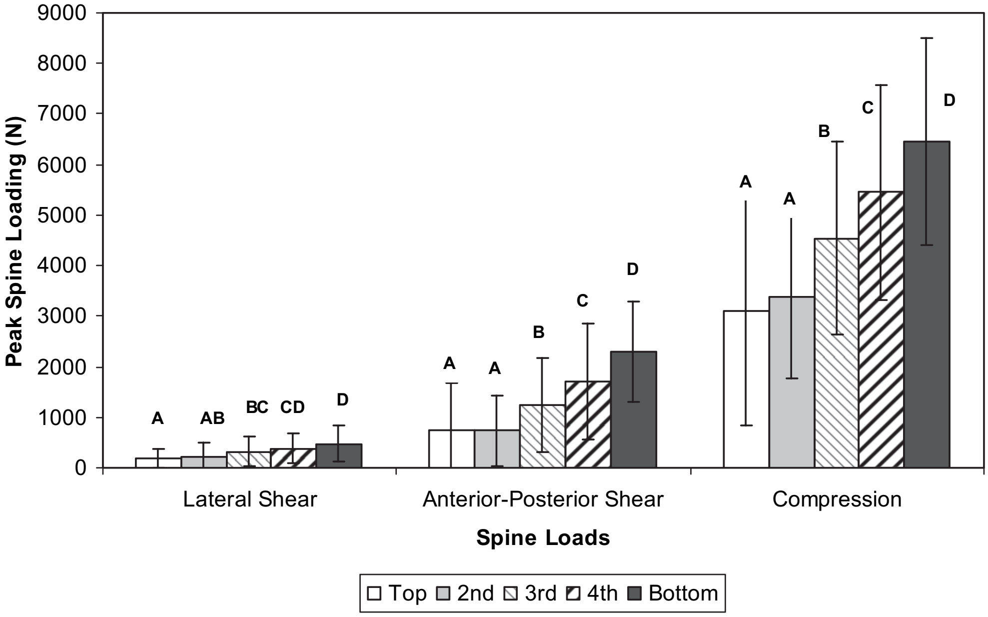

Fig. 3. Peak three-dimensional spine loads as a function of height of bags at the origin of the lift (Different alpha characters indicate significant differences at the 0.05 significance level as determined by Tukey post-hoc test). Error bars are standard deviations.

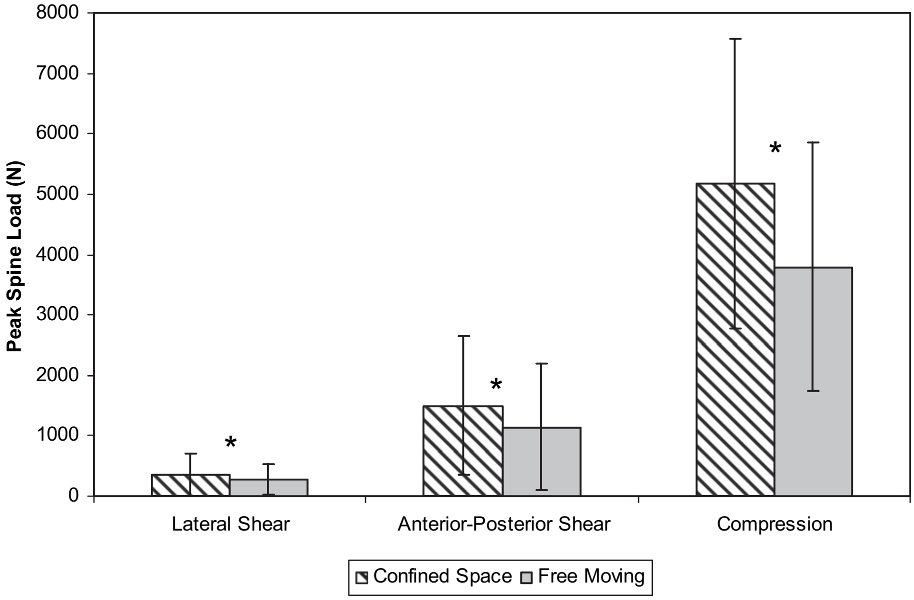

Fig. 4. Peak three-dimensional spine loads as a function of lifting type. (* indicates a significant difference between confined lifting and free moving lifting). Error bars are standard deviations.

interacted with the bags during the lift. Another factor that may have influenced the resulting trunk moment and spine loads may be the trajectory of the bag during the lift. While there are no data available on the actual pathway of the bag, biomechanics principles would indicate that how the bag moved both dynamically and actual pathway (e.g. changes in the moment arm between the bag and spine) would directly influence the resulting spine loads.

One additional difference between the two bags was the muscle coactivity pattern. For the main extensor muscles (right and left erector spinae, internal obliques, and latissimus dorsi), the large (42.7 kg) bags had higher levels of muscle activity as compared to the small (21.4 kg) bags (about 15% MVC). The flexor muscles (right and left rectus abdominus and external oblique muscles) activity level was about 5% MVC higher for the large bags as compared to the small bags. Thus, while there was a 50% increase for weight lifted fro the large bags, there was not a corresponding 50% increase in the muscle coactivation, partially explaining the modest difference (about 25%) between the small and large bags for the spine loads. In all, the results indicate that reducing the weight is not a simple reduction of the spine loads. Many factors may have contributed to the loads resulting from the small and large bags including trunk moment due to the upper body that likely remains relatively consistent between conditions, muscle coactiviation that was altered, and the trajectory of the box that may have changed.

The spine loads are on similar magnitudes to those found for lifting box weights in a warehousing depalletizing task, as reported by Marras et al. (1999). These authors evaluated lifting boxes weighing 18.8 kg and 22.7 kg (similar to the small bags) from different heights on the pallet. On average, the compression loads for the 18.8 kg and 22.7 kg when lifting from the lower-front parts of the pallet were approximately 2000 to 4000 N and 2400 to 4500 N, respectively. In the Marras study, the participants lifted while their feet were able to move which is similar to the free moving conditions of the current study. For the free moving lifting conditions with the 21.4 kg bags, the compression loads were ranged from 2100 N for the top row to 3500 N for the middle row to 5300 N for the bottom row. Thus, the current study had slightly higher compressive loads potentially due to lifting from slightly

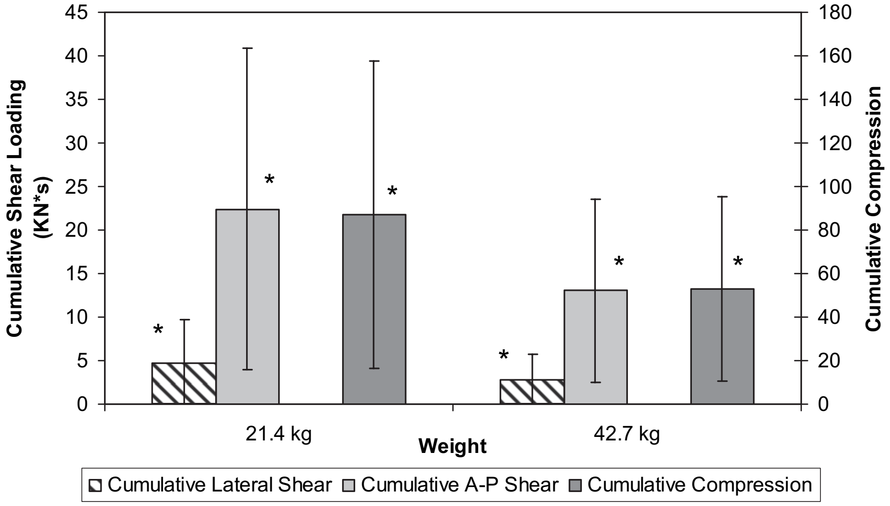

Fig. 5. Cumulative three-dimensional spine loads as a function of bag weight (21.4 kg vs. 42.7 kg). Error bars are standard deviations.

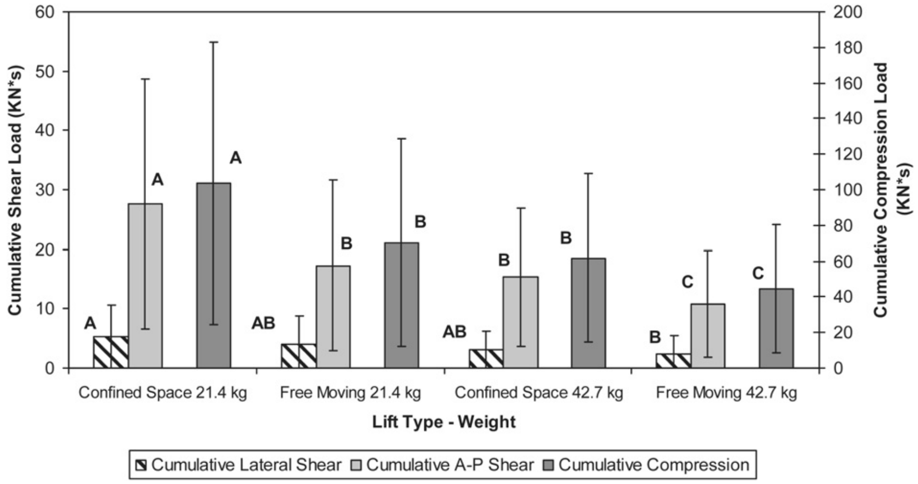

Fig. 6. Cumulative three-dimensional spine loads as a function of bag weight (21.4 kg vs. 42.7 kg) and lifting type (confined space vs. free moving of feet). Error bars are standard deviations.

different heights on the pallet as well as lifting bags instead of boxes which may be slightly more unstable. The position of the hands on the object could have also contributed to the differences (e.g. height of bags is lower than height of boxes).

Several other factors relating to where the bags were positioned and how they were lifted influenced the three-dimensional loads on the spine. First, the direction that the bags were lifted made a difference on the lateral shear forces with higher forces when lifting to the right (about 30%). This directional difference has also been seen previously where Marras and Davis (Marras and Davis, 1998) found lifting from right asymmetric origins produced higher loads than when lifting from the left. While the current study evaluated lifting to asymmetric destinations, the results support the notion that lifting to the right produce higher loads than lifting to the left. These results appear to be a result of a combination of differences muscle activity. Lifting from the right position produced more muscle activity in the right latissimus dorsi (5% MVC), left external oblique (14% MVC), and Left internal oblique muscles (10% MVC). Second, lifting the bags from lower heights significantly increased the three-dimensional spine loads. The peak load results indicate that lifting bags from the lowest levels (or horizontal origins), either from the pallet or stacked on one bag, produced extremely high shear and compressive loads. The current study provides further support to previous studies that indicated that lifting above the waist level is imperative to minimizing the spine loads. Similar results have also been found for lifting at lower heights in warehousing situations (Borg, 1982). Thus, the impact of the large bags was magnified at the lower lifting positions. Based on the trunk kinematics, the lower positions significantly produced more awkward postures and faster lifting motion. When the bags were lifted off the top of the pallet or on one bag above pallet, the sagittal flexion was greater than 60°, indicating extreme postures when lifting the bags from these levels. Further, the participants adopted faster motions with sagittal velocity approaching more than 85°/s. Simple interventions such as placing multiple pallets under the bags could raise the bags to safer heights where sagittal flexion and motion can be significantly reduced. The key is to not only reduce the bag loads but also raise them above knee height or even better near waist height.

Third, the placement of the feet when a mason tender moves the bags also impacts the loads on the spine. The lifting conditions where participants were not able to move their feet produced significantly greater three-dimensional spine loads (approximately 20–25% more) than when they were able to freely move their feet. Basically, by moving their feet, the mason tenders were able to move closer to the bags and reduce awkward postures and trunk motion (about 7° sagittal flexion and 10°/s sagittal velocity) as compared to the feet stationary conditions. As a result, the activity of multiple muscles were also reduced including right and left erector spinae (about 4% and 10% MVC) but increase in other muscles (right and left latissimus dorsi (about 5% MVC), left rectus abdominus (7.5% MVC), right external oblique (about 6% MVC), and left internal oblique muscles (4% MVC)). As a result, the loads on the spine are reduced during the free movement of the feet. The feet stationary conditions would resemble conditions where there are confined spaces or obstacles in the way of the workers. The results provide strong evidence that it is important to be in lifting positions that allow the lift to be performed while the feet can move and pivot.

Overall, the peak loading results indicate the importance of reducing the bag weight, raising the bags from low positions, and allowing the feet to move freely during the lift. As loading increase on the spine structures, there are many mechanisms that can fail and cause an injury, including intervertebral discs, endplates of the vertebral body, facet joints, fascia, and muscle. There have been several studies to benchmark structural failure in the disc based on compressive and shear load limits. When the peak compression loads were compared to known tolerance levels (Waters et al., 1993) of 3400 N for a lower benchmark (some workers begin to have damage to intervertebral disc and endplate) and 6400 N for an upper benchmark (most workers start to have damage to intervertebral disc and endplate), the spine compression loads are put into a perspective that makes it clear that lifting the large bags from lower levels significantly increases the probability of a low back injury (Table 2). In addition, the A–P shear loads were compared to the estimated shear tolerance of 1000 N where fibers of the disc failed (as defined by McGill, 1996) It becomes very apparent from the table that the lowest levels (or horizontal origins), large bags, and fixed feet position significantly increase the number of lifts that exceed the upper compression tolerance limits, in many cases approaching 75% of the lifts. The lower regions exceed the shear threshold even more often with the percentage exceeding the limits approaching 90–95% for the large bags (confined spaces and free moving) and small bags (confined space lifting). The table also indicates that the risk of low back injury would be minimized when lifting the small bags (light weight) from the top of a five bag stack and to a lesser extent from the 2nd from the top and middle bag levels. The bottom line is that mason tenders need to lift bags from the upper rows and farther off the ground, which may be

Table 2
Percentage of lifts for the different bag weights when lifted from different height levels that exceed the compression benchmarks of 3400 N and 6400 N and anterior–posterior shear benchmarks of 1000 N.

Row		21.4 kg bags		42.7 kg bags	
		Free moving feet	Confined space	Free moving feet	Confined space
Compression benchmark					
Top of stack	0–3400	72.5%	50.0%	75.0%	55.0%
	3400–6400	25.0%	37.5%	20.0%	30.0%
	>6400	*2.5%*	*12.5%*	*5.0%*	*15.0%*
2nd from top	0–3400	60.0%	37.5%	65.0%	45.0%
	3400–6400	32.5%	55.0%	30.0%	50.0%
	>6400	*7.5%*	*7.5%*	*5.0%*	*5.0%*
Middle	0–3400	57.5%	30.0%	40.0%	5.0%
	3400–6400	37.5%	57.5%	45.0%	75.0%
	>6400	*5.0%*	*12.5%*	*15.0%*	*20.0%*
2nd from bottom	0–3400	50.0%	25.0%	25.0%	5.0%
	3400–6400	35.0%	42.5%	50.0%	45.0%
	>6400	*15.0%*	*32.5%*	*25.0%*	*50.0%*
Bottom of stack	0–3400	30.0%	10.0%	0.0%	0.0%
	3400–6400	57.5%	55.0%	65.0%	20.0%
	>6400	*12.5%*	*35.0%*	*35.0%*	*75.0%*
Anterior–posterior shear benchmark					
Top	>1000 N	5.0%	15.0%	15.0%	30.0%
2nd from top		7.5%	20.0%	20.0%	15.0%
Middle		37.5%	40.0%	40.0%	45.0%
2nd from bottom		50.0%	72.5%	65.0%	75.0%
Bottom of stack		80.0%	95.0%	95.0%	90.0%

accomplished by stacking multiple pallets on top of each other or building small platforms. Further, the lighter bags were also found to minimize the peak loads.

While the results for peak loading indicate that the lighter bags (small bags) reduced the spine loads under certain lifting conditions, the cumulative load results provided a slightly different picture. Given that two small bags had to be lifted for every large bag, the time to complete the lifting of equivalent amounts of material (e.g. same weight) was more for the small bags. Based on lifting bags of mortar mix, the average time to move all bags for the small bags (20 bags) was 67.66 s as compared to the large bags (10 bags) of 40.24 s. Basically, when lifting the same amount of material (e.g. 427 kg of mortar), the small bags required about 27 s longer or a 68% increase in total time. As a result, the cumulative loading exposure was found to be higher for the small bags (about a 70% increase in the three-dimensional loads). While Norman et al. (1998) reported cumulative spine loading (A–P shear and Compression) as an indicator for risk for low back injuries in industry, there are no benchmarks to determine whether these levels of cumulative load are sufficient enough to cause damage. Thus, while the cumulative loads for the small bags are greater than the large bags, the magnitude of the cumulative loads may or may not be sufficient enough to cause substantial damage. However, the cumulative loading results indicate that a reduction of bag weight may not totally place the mason tenders are minimal risk of a back injury. Other interventions such as equipment to lift the bags may be necessary to mediate further the risk of injury by reducing the loads on the spine through reduction of the weight being lifted, especially for the lower lift heights.

From a physiological perspective, there was no difference between the light (21.4 kg) and heavy (42.7 kg) bags for either heart rate or blood pressure. There are a couple of potential explanations for this lack of a physiological difference. First, the number of bags being lifted over this short duration was not sufficient to produce changes between the two bag sizes. In other words, changes in the kinematics that resulted for the small bags may have been offset by the greater weight of the large bags which made it impossible to detect a difference in the physiological measures. Second, the duration may not have been sufficient enough to produce fatigue or stress the cardiovascular system of seasoned (experienced) mason tenders. The participants, for the most part, were use to lifting significant amounts of weight during the day. So when they were required to perform the study lifts, the demands were not above levels for which they were normally conditioned. Third, the measures that were used were relatively crude whole-body measures (blood pressure and heart rate measured at arm while standing still). More sensitive measures such as muscle oxygenation or even oxygen consumption at the whole-body level may provide a better indication of the physiological stress being placed on the mason tenders.

Another important outcome indicator is the perceptions of the mason tenders with respect to the exertion level, risk of injury, and preference of bag size when lifting. Overall, the participants rated their perceived exertion (RPE) during the lifting of small bags as being significantly lower than that of the large bags (by a difference of 3.6 for a 6–20 scale). Similarly, the perceived risk of injury (TRR) for the small bags was significantly lower than the large bags (a difference of 2.8 on scale 1–10). These differences in perception represent a large decrease in effort and risk for the mason tenders when lifting the small bags. Finally, each subject was asked a simple question at the end of the study about which type of bag they preferred to lift. Nine out of 10 participants preferred to lift the small bags than large bags, even with the additional lifts for small bags. The fact that all but one of the participants indicated that they preferred to lift the small bags indicates that this type of intervention would be well received on site. Overall, the perceptions of the participants supported the results of the peak spine loads where the small bags were better than the large bags.

While the majority of the results were found to be favorable towards the universal adopting of small bags to transfer masonry materials, there are a few other considerations that need to be addressed. First, all the subjects were male with an average weight of 99.8 kg (SD = 18.3 kg). Thus, these were large males that were most likely above average in muscle strength relative to the general population. As a result, the small bags may be even more suitable for small workers, particularly females who may not have the strength to lift the large bags repeatedly.

Second, the conditions represented a simulation of mason tenders transferring masonry materials. In typical industry conditions, workers may not continually lift bags but perform lifting on a more sporadic schedule throughout the day. In addition, the environmental conditions in the laboratory were more optimal than what would traditionally be found on site. For example, the laboratory simulated work area was dry, a comfortable temperature, and free of sand, mud, and other materials that make lifting more difficult to perform. However, the simulation was conducted to have conditions that would allow the experimental factors to be compared on an equal basis without variability due to the environment. In all, the laboratory simulation of the task provided a realistic assessment of the lifting demands of mason tenders utilizing small and large bags.

Third, with the addition of more bags and lifts for the small bags, it is important to understand the cost trade-offs that may occur when switching to the small bags. Obviously, when lifting the same amount of masonry material, the small bags will require twice as many bags and take longer to move. The amount of time required to lift the small bags was 68% longer when lifting the same amount of total weight. Based on the data from Vi et al., (Vi, 2007) the average time spent handling large bags on commercial and residential sites was approximately 1.0% of the working time. Using a conservative 2000 h per year for a fulltime employee, the amount of time for the small bags would be 33.6 h as compared to

20 h for the large bags. The increased labor costs for the small bags would be $483 (assuming average local cost of $35.56/hr). Material costs for the bags would also increase based on the average price of $2.87 for small bags and $4.72 for large bags. In a given year, mason tenders would carry 25 large bags or 50 small bags per day, a total of 6250 large bags or 12,500 small bags. The difference in bag cost is an increase of $6375 for the small bags. Thus, the total increase in cost for the small bags would be $6858 per year. However, the elimination of one back injury would almost completely offset this cost increase (according to BWC data, an average low back injury case costs approximately $11,870) (Dunning et al., 2008). Thus, the cost justification would be whether the reduction in the peak A–P shear and compression loads is sufficient to eliminate an injury to one worker. While it is unlikely to have a sustained reduction of one low back injury each year, the costs of elimination just one would significantly offset the increased costs of the small bags. There is some indication that the risk of a low back injury was reduced when lifting the small bags, particularly at the higher rows while allowing the feet to freely move, potentially indicating such a reduction may be injuries is possible for large companies (see Table 2).

Finally, the cumulative load values are under-estimates of the total cumulative loading since only the lifting phase of the task was evaluated and analyzed. While this would represent the bulk of the expected loading during active lifting of the bags, the estimates neglect the unloaded phases before the bags were picked up and after the bag was placed down. As a result, the cumulative load estimates would be higher if the entire work cycle was evaluated. The addition of the non-active lifting phase would likely have increased the differences between the small and large bags since the small bags will have more lifts and more unloaded time during work cycle. However, much of the differences in cumulative loading between small and large bags could be “washed out” due to the portion of overall time that handling mason bags relative to all the tasks being performed by masons. Relatively, the handling of mason bags most likely represents a small proportion of the overall exposure (less than 1% of time (Vi, 2007)) and risk for the low back.

4.1. Implications for the construction sector

In practice, the use of small bags may be one feasible intervention for one low back risk exposure for mason tenders. While lifting large bags of mason material occurs relatively infrequently throughout the workday, the peak loads were substantial and may pose significant risk to mason tenders. The small bags reduced the spine loads significantly but not completely in half compared to the large bags. Mason tenders will also need to understand how they interact with the bags significantly alters the loading on the spine and ultimately the risk of low back injuries. Lifting small bags from above waist level with the ability to move their feet results in the best lifting technique and minimize the spine loads. The exciting part about the potential adoption of small bags as an intervention on the construction site was the “buy-in” by the mason tender where nine out of ten stated they preferred the small bags to move the material. Perception can play a huge role in whether an intervention will be adopted in practice. Thus, the small bag intervention appears to be a viable intervention for a task that poses significant low back risk to mason tenders.

5. Conclusion

The current study provides some insight into the utility of lighter weight bags in reducing the loads placed on the lower back during lifting of masonry material. Based on the peak loads, the small bags reduced the spine loads by 25% as compared to the large bags. On the other hand, the cumulative loads were actually greater for the small bags due to the necessity to lift more bags to equal the same amount of weight. While there was a trade-off between peak and cumulative spine loads, the small bags, particularly when lifted from the top rows and allowing the feet to move freely, reduced the overall loading on the spine. At the current time, there is not a good enough understanding of the tolerances for peak vs. cumulative loads to make a definitive recommendation that the small bags result in minimal risk for masons. As such, the loads on the spine resulted from a combination of the loads due to body weight (upper torso) and weight of the bags. Regardless of bag weight, poor work station—bag placement near ground level and obstructed foot movement—increased loading and potential injury risk. Further, the perceptions of the mason tenders favored the small bags with respect to perceived exertion level, risk, and preference to lift. As a result, mason tenders may be more receptive to the small bags as an intervention.

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