International Journal of Industrial Ergonomics

International Journal of Industrial Ergonomics 23 (1999) 505–511

Analysis of biomechanical stresses during drywall lifting

Christopher S. Pan*, Sharon S. Chiou

Division of Safety Research, National Institute for Occupational Safety and Health, 1095 Willowdale Rd., Morgantown, WV 26505, USA

Received 10 July 1997; received in revised form 10 October 1997; accepted 14 October 1997

Abstract

Constant lifting of massive and bulky drywall sheets creates overexertion hazards among drywall installers. The objective of this study was to gain understanding of the biomechanical stresses imposed on the workers while lifting drywall sheets. A video analysis was performed to identify current drywall lifting techniques. Computer simulations of these techniques for lifting drywall sheets of 60, 80, and 100 lb were then conducted to estimate the biomechanical loadings on the workers. Four lifting methods were determined to be the most commonly used drywall lifting techniques. The University of Michigan Three-Dimensional Static Strength Prediction Program (3DSSPP™) was used for the simulations. It was found that all four lifting techniques produced considerable biomechanical stresses at the workers' shoulders, torsos, and hips. Only a limited percentage of the male population has sufficient strength capability to perform the task. The estimated L5/S1 and L4/L5 disc compression forces were consistently high, ranging from 655 to 1363 lb for various loads and postures analyzed. Results from this study provided evidence regarding the biomechanical stresses associated with drywall lifting. Further studies are recommended to identify less stressful drywall lifting methods and to develop safe assistive devices to reduce overexertion injuries.

Relevance to industry

There is an increasing tendency toward awareness of ergonomic issues in the construction industry. One area of the construction industry – drywall installation – has been troubled with overexertion injuries. Lifting massive and bulky drywall sheets increases the risk of overexertion injuries. Prior to this study there has been little substantive research to quantify the excessive stresses imposed on drywall installers.

Keywords: Lifting; Biomechanical stresses; Drywall installation; Traumatic injuries

1. Introduction

Lost-work-time injuries in construction rank among the highest in United States industries. In 1994, the lost-work-day injury incidence rate in the construction industry was 5.4 per 100 full-time-employees, which was higher than that of all other major industries (Bureau of Labor Statistics, 1997). The estimated traumatic injury incidence rates for drywall installers were 7.7 and 5.4 per 100 workers for 1992 and 1993, respectively (Chiou et al., 1997). These rates were higher than that of all construction workers combined (5.2 for 1992 and 4.9 for

* Corresponding author.

0169-8141/99/$ – see front matter
PII: S0169-8141(97)00016-X

1993). A recent study of injury characteristics of drywall installers indicated that drywall installers were at high risk for overexertion injuries. Nearly half of the injured drywall installers suffered sprains, strains, and tears mostly to the back. About one-third of the trunk injuries occurred while lifting solid building materials, mainly drywall (Chiou et al., 1997).

Drywall installation involves many different types of material handling activities, which can be categorized into four major tasks: (1) hanging drywall on ceilings and walls; (2) applying tape to joints and corners; (3) applying skim coats of joint compound; and (4) sanding skimmed drywall. Among 30 common construction specialties, drywall installers are ranked as one of the top four occupations that are at increased risk of occupational injury, based on the workers' compensation data of 21 states (Hsiao and Stanevich, 1996). Only construction laborers, carpenters, and roofers ranked higher. In a focus-group study, drywall installation was considered to be one of the two most difficult carpentry specialties (Warren et al., 1994). Lifting and carrying drywall sheets were reported as the most difficult tasks by carpenters who performed drywall installation.

Handling massive and bulky drywall sheets is a task that increases the risk of overexertion injuries during drywall installation. A typical drywall sheet weighs between 51 and 109 lb and is 4 ft wide and 8–16 ft long. Since these sheets have no handholds and are less than 1 in thick (ranging from 3/8 to 5/8 in), it is not easy for workers to grasp them efficiently and adequately to support the heavy weight. Therefore, handling sheets exposes workers to potential hazards and injuries (Schneider and Susi, 1994). Some drywall installation tasks, such as lifting, carrying, or hanging the drywall sheets, require considerable muscle force and may force the worker to adopt awkward working postures. The high musculoskeletal load imposed on the worker may result in muscle fatigue, or over a longer time period, in musculoskeletal trauma disorders and chronic muscle pain (Mital et al., 1993).

Drywall installers only represented approximately 1.42% of the construction workforce in 1992. However, drywall installation tasks are commonly performed by carpenters, which represent 1.07 million workers. Drywall handling tasks are also performed by various other groups, such as laborers in warehouses. Although there is increased concern about work-related musculoskeletal injuries associated with drywall handling, the overexertion hazards of manually handling drywall sheets and possible injury-reduction methods have not been well explored. The objective of this study is to gain an understanding of the biomechanical stresses imposed on the workers while lifting drywall sheets.

2. Method

A video analysis of actual drywall installation was performed to identify current drywall lifting methods. The videotapes were obtained from five construction site visits in southern Ohio and northern West Virginia, involving eight drywall installers (mean age: 42.1 ± 12.1 yr), for a total duration of 7 h and 20 min. All eight workers observed were male with drywall installation experience ranging from 1 to 43 yr (mean = 18.9 yr). The videotapes contain workers' activities during their work routines. The observed normal work routines included the tasks drywall installers were doing on the day they were observed at the construction sites. In general, the tasks observed from videotapes were (1) cutting and measuring drywall; (2) lifting and carrying drywall; and (3) hanging drywall to the wall and ceiling. Since drywall lifting was identified as the most hazardous task in causing traumatic injuries to drywall installers (Chiou et al., 1997), this study only focused on the biomechanical stresses associated with drywall lifting.

After reviewing all the videotapes, four primary lifting methods employed in drywall handling were identified as shown in Fig. 1. For method 1, the worker lifted a drywall sheet oriented vertically, with arms slightly extended, and held below shoulder level; this was the most common posture workers employed to adjust the drywall sheet in place before it was fastened to the wall. Lifting method 2 involved a worker lifting and grasping a horizontally oriented drywall sheet with palm down and arms raised above shoulder height, while method 3 involved handling the horizontal drywall

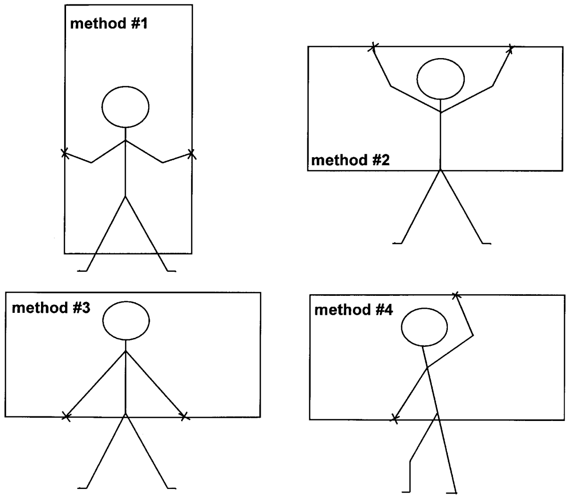

Fig. 1. Illustration of four drywall lifting methods.

with palm up and arms below shoulder level. For lifting method 4, the worker used one hand to support the horizontal drywall sheet at its bottom and the other hand to grasp the sheet at its top. The torso of the worker was slightly twisted. Methods 2–4 were often used by the worker to load or unload drywall sheets onto a cart or dolly. The worker first tilted the drywall sheet toward its upright position and then used either method 2, 3, or 4 to lift and carry it to a destination. The worker usually used the same carrying methods that he used to lift the drywall sheets.

The postures associated with each of the four identified lifting methods were reconstructed in the University of Michigan 3D Static Strength Prediction Program (3DSSPP^{TM}) to estimate the disc compression forces as well as the percentage strength limits (University of Michigan, 1995). In addition to predicting L5/S1 disc-compression force based on the assumption of sagittal symmetry, the more advanced three-dimentional back analysis was used to predict L4/L5 disc compression force (see Bean et al., 1988; Chaffin et al., 1987; Chaffin and Erig, 1991; Chaffin and Andersson, 1991; Garg et al., 1982 for details). The predicted L5/S1 and L4/L5 disc compression forces were then compared to Back Compression Design Limit (BCDL) of 770 lb and Back Compression Upper Limit (BCUL) of 1430 lb as differentiated from the National Institute for Occupational Safety and Health (NIOSH) Action Limit (AL) and Maximum Permissible Limit (MPL) (NIOSH, 1981). Also, the strength limit predictions were referenced to Strength Design Limit (SDL) and Strength Upper Limit (SUL) as differentiated from the NIOSH AL and MPL. The SDL or BCDL represents 99% male and 75% female population capability, and SUL or BCUL represents 25% male and 1% female population capability for the amount of weight lifted with the certain posture (Chaffin and Andersson, 1991).

The analyses were performed under the assumption that the lifting motions were smooth. In addition, the load distribution to both hands was assumed to be equal and the force was considered to be directly vertical and downward. Computer-aided figures were manipulated until their postures closely matched the postures identified from the videos. For each lifting method, one specific posture was reconstructed based on the observations of the eight workers at the moment when the drywall was first lifted. The posture was considered to present the most stressful of all postures studied, in that the arms were most fully extended and the weight was furthest from the bodies' center of mass. The weight loads of 60, 80, and 100 lb were analyzed. These loads represented typical drywall sheets measuring 4 ft wide, 8–12 ft long, and 1/2 in thick. The worker anthropometry was set for a 50th percentile male with a weight of 165.6 lb and a height of 69.7 in. With the biomechanical stress information estimated by the computer program, the drywall lifting methods which imposed significant stress on the worker as well as on the individual body parts were identified.

3. Results

Based on the video analysis, lifting method 1 was found to be the most commonly used drywall lifting technique among the subjects studied. Lifting methods 1–4 accounted for 40%, 7%, 23%, and 30% of the observed drywall lifts, respectively. Method 1 is normally seen in installations in large commercial buildings or residential buildings of

Table 1
Estimated percentage of male population with sufficient strength capability to lift a 60, 80, or 100 lb drywall sheet

Body parts	Method 1			Method 2			Method 3			Method 4		
	60 lb	80 lb	100 lb	60 lb	80 lb	100 lb	60 lb	80 lb	100 lb	60 lb	80 lb	100 lb
Elbow	94	80	62	98	84	70	99	96	88	99	94	84
Shoulder	97	91	77	95	83	60	93	79	53	93	71	36
Torso	95	91	84	96	93	88	97	95	93	94	91	86
Hip	93	89	84	94	91	87	92	89	85	83	75	65
Knee	99	99	99	99	99	99	98	98	98	97	97	98
Ankle	99	98	97	98	97	95	99	99	99	99	99	99

a ceiling height around 8 ft, where the drywall sheets are usually hung vertically. Methods 2–4 are often used in the construction of residential buildings where the drywall sheets are applied horizontally to avoid joints and reduce taping and finishing work.

Table 1 shows the percent of the male population with sufficient strength to lift 60, 80, and 100 lb drywall sheets. All four lifting techniques produced biomechanical stresses greater than the SDL at drywall installers' shoulders, torso, and hips, indicating that less than 99% of adult males in the population were estimated to have enough shoulder, torso, and hip strength to perform the task. Lifting a 100 lb drywall sheet using methods 3 and 4 placed excessive stresses on the worker's shoulders. Only 53% and 36% of the male population were estimated to have sufficient shoulder strength to perform lifting methods 3 and 4, respectively, with a 100 lb sheet. In contrast to other methods, lifting methods 1 and 2 created greater stresses on the workers' elbows and only about 60–70% of the adult males in the population would have enough elbow strength to lift a 100 lb drywall sheet. With regard to torso strength, lifting method 3 appeared to create less biomechanical stress in that more than 90% of the male population were able to perform the task. In comparison with other methods, lifting a drywall sheet using method 4 requires relatively high hip strength. Only 65% of male population have sufficient hip strength to lift an 100 lb drywall sheet using method 4, while more than 80% of adult males have enough hip strength to perform the task using other methods.

The fraction of people capable of lifting a drywall sheet decreased as the weight of the drywall increased. It was estimated that more than 90% of males would be able to lift a 60 lb drywall sheet using methods 1–3, but only 83% of the male population could perform the task using method 4, due to the stresses on the workers' hips. Over 50% of male adults were predicted to have enough strength to lift a 100 lb drywall sheet with methods 1–3, but only 36% of the male population have enough shoulder strength to accomplish the task using method 4.

Tables 2 and 3, respectively, present the estimated L5/S1 and L4/L5 disc compression forces for the four methods and three different weights of drywall sheet. The results from both L5/S1 and L4/L5 disc compression forces indicate a consistent tendency for the four lifting methods and three different weights of drywall sheet. When a 100 lb drywall sheet is lifted, the worker low back loadings exceeded the BCDL of 770 lb recommended by the NIOSH Work Practices Guide for Manual Lifting. The estimated disc compression forces did not exceed BCDL when a 60–80 lb drywall sheet was lifted using either method 1–3. Using these methods to lift a 60 or 80 lb drywall sheet, however, placed considerable stress on the worker's torso (Table 1). Method 4 appears to be the most hazardous to the back among all lifting methods. Even lifting a 60 lb

Table 2
Estimated L5/S1 disc compression forces (lb) resulting from the lifting of a 60, 80, or 100 lb drywall sheet

	Weight of drywall		
	60 lb	80 lb	100 lb
Method 1	655	734	830
Method 2	649	757	857
Method 3	659	750	836
Method 4	915	1072	1228

Table 3
Estimated L4/L5 disc compression forces (lb) resulting from the lifting of a 60, 80, or 100 lb drywall sheet

	Weight of drywall		
	60 lb	80 lb	100 lb
Method 1	758	853	966
Method 2	742	863	976
Method 3	726	827	925
Method 4	921	1187	1363

drywall sheet placed considerable stress exceeding the BCDL, when method 4 was involved.

4. Discussion

This study has shown that four current methods for lifting massive and bulky drywall sheets create overexertion hazards among construction workers. In addition, the results of this study have suggested that Method 4, compared with the other three methods, appears to be the most stressful. There is an increasing trend toward awareness of ergonomic issues in the construction industry, especially as concerns drywall installation (Schneider and Susi, 1994). There has been a significant amount of research on the association between drywall installation and illness (Fischbein et al., 1978, 1979; Freed et al., 1991). However, very little research has been conducted to examine possible injury scenarios and to reduce occupation-related ergonomic hazards associated with lifting drywall sheets. The lack of current data is of great concern. The findings of this study provide some understanding of drywall lifting and also point out future research that needs to be conducted to reduce the overexertion risks associated with drywall installation.

Results from this study (Table 1) indicate that the four lifting methods placed considerable stress on the worker's shoulders, torso, and hips – only a limited percentage of the general male population has sufficient trunk strength to perform the task. It should be noted that shoulders, torso and hips were included in the trunk group in the part-of-body-affected classification used by the Bureau of Labor Statistics. This finding of limited strength in the general male population is consistent with BLS traumatic injury data for drywall installers – of all body regions, the trunk was most frequently injured, accounting for 36.0% of the traumatic injuries, followed by upper extremity injuries (26.0%) for the period of 1992–1993 (Bureau of Labor Statistics, 1995). More specifically, the back was the most frequently injured body part, and accounted for 26.9% of traumatic injuries that occurred to drywall installers for 1992 and 1993.

During heavy lifting loads, it is evident that the highest compressive forces on the vertebral column are in the lowest five lumbar vertebrae and sacrum (Chaffin et al., 1977; Grendjean, 1989). Degenerative discs in the vertebral column are the usual suspect in causing back injuries, especially with pre-existing low back disorders (Chaffin et al., 1977; Grendjean, 1989). Therefore, some researchers have considered the L5/S1 disc as the weakest link of the body segments when performing heavy lifts (Ayoub and Mital, 1989). Compared with the other three lifting methods, the results of this study indicate that lifting method 4 resulted in higher L5/S1 and L4/L5 disc compression forces. The L5/S1 and L4/L5 disc compression forces in lifting method 4 exceed the BCDL (770 lb), ranging from 915 to 1363 lb for the loads analyzed (Tables 2 and 3). In Table 3, the higher L4/L5 disc compression force for lifting method 4 might be due to the fact that twisted and asymmetric postures were involved, resulting in an increase in the moment of loading on the trunk. Another interesting result of this study is that the L5/S1 disc compression forces were lower than the BCDL when lifting methods

1–3 were involved and the loads were under 80 lb (Table 2). This outcome may have resulted from the fact that the drywall sheets were held very close to body. In this regard, Chaffin and Andersson (1991) recommended that lifting a load as close to the trunk as possible, which already seems to be occurring in this work force.

There are some limitations to this study. The current study applied a static biomechanical model to a dynamic drywall lifting task without consideration of the acceleration and momentum associated with lifting. Such situations may result in the underestimation of stresses on the musculoskeletal system and of injury risks associated with lifting drywall sheets (Mital and Kromodihardjo, 1986; Marras et al., 1995). Another limitation is that the assumption of the analyses about the vertical and downward forces might not exactly reflect real working conditions. A future follow-up study will be performed at NIOSH to examine the kinetics and kinematics associated with drywall lifting. In the current study, a small number of subjects was observed, so the study results may not be generalized to a large population. Another study limitation is that the biomechanical analysis (University of Michigan, 1995) only accounts for the exposures of loads and postures. Other exposures such as frequency and duration (Marras et al., 1995; Bhattacharya et al., in press), as well as physiological factors, may have impact on drywall installation-related injuries.

In summary, based on the results from this study for the estimated strength capabilities and disc compression forces, all four lifting methods tended to produce considerable biomechanical stresses at the workers' shoulders, torsos, and hips. To reduce the risk of overexertion injury for the drywall installation workforce, assistive devices and redesign of the size of drywall sheets may deserve consideration. There are a variety of ergonomic assessment methods and instruments available for assessing hazardous tasks and activities for lifting. However, due to the dynamic nature of construction activities, there are many practical limitations to performing accurate, non-invasive and reasonably priced ergonomic assessment instruments at the worksite. Therefore, future study is needed to identify the most reliable exposure assessment methods, evaluate possible ergonomic solutions, and recommend the safest, biomechanically sound handling methods for construction workers and other related laborers. Currently, a NIOSH drywall-installation survey is being conducted to collect a range of injury information from drywall installers, which is not limited to injury directly related to drywall lifting. In addition, a BLS injury-database analysis is being conducted at NIOSH to increase the understanding of drywall installation-related injuries and help formulate injury prevention strategies.

Acknowledgements

The authors would like to thank Paul Keane for his editorial comments on various versions of this manuscript. We gratefully acknowledge Richard Hughes and Hongwei Hsiao, who have reviewed and commented on this manuscript at various stages.

References

Ayoub, M.M., Mital, A., 1989. Manual Materials Handling. Taylor & Francis, London, England.

Bean, J.C., Chaffin, D.B., Schultz, A.B., 1988. Biomechanical model calculation of muscle contraction forces: a double linear programming method. Journal of Biomechanics 21, 59–66.

Bhattacharya, A., Greathouse L., Warren, J., Li, Y., Dimov, M., Applegate, H., Stinson, R., Lemasters, G. (in press). An ergonomic walkthrough observation of carpentry tasks: a pilot study. Applied Occupational and Environmental Hygiene Journal.

Bureau of Labor Statistics, 1995. Occupational Injuries and Illnesses: Counts, Rates, and Characteristics, 1992: US Department of Labor, Bulletin 2455, US Government Printing Office Washington, DC.

Bureau of Labor Statistics, 1997. Occupational Injuries and Illness: Counts, Rates, and Characteristics, 1994: US Department of Labor, Bulletin 2485, US Government Printing Office Washington, DC.

Chaffin, D.B., Andersson, G., 1991. Occupational Biomechanics. 2nd ed., Wiley, New York.

Chaffin, D.B., Herrin, G.D., Keyserling, W.M., Garg, A., 1977. A method for evaluating the biomechanical stresses resulting from manual material handling jobs. American Industrial Hygiene Association Journal 38, 661–675.

Chaffin, D.B., Freivalds, A., Evans, S.M., 1987. On the validity of an isometric biomechanical model of worker strengths. IIE Transactions 19 (3), 280–288.

Chiou, S., Pan, C.S., Fosbroke, D.E., 1997. Identification of risk factors associated with traumatic injuries among drywall installers. In: Das, B., Karwoski, W. (Eds.), Advances in Occupational Ergonomics and Safety. IOS Press, Amsterdam, pp. 377–380.

Fischbein, A., Langer, A.M., Suzuki, Y., Selikoff, I.J., 1978. Carcinoma of the lung in a drywall taping worker report of a case. Toxicology Letters 2, 231–236.

Fischbein, A., Rohl, A.N., Langer, A.M., Selikoff, I.J., 1979. Drywall construction and asbestos exposure. American Industrial Hygiene Association Journal 40, 402–407.

Freed, J.A., Miller, A., Gordon, R.E., Fischbein, A., Kleinerman, J., Langer, A.M., 1991. Desquamative interstitial pneumonia associated with chrysotile asbestos fibres. British Journal of Industrial Medicine 48, 332–337.

Garg, A., Chaffin, D.B., Freivalds, A., 1982. Biomechanical stress from manual load lifting: a static vs dynamic evaluation. IIE Transactions 14 (4), 272–280.

Grendjean, E., 1989. Fitting the Task to the Man. 4th ed, Taylor and Francis, London.

Hsiao, H., Stanevich, R.L., 1996. Injuries and ergonomic applications in construction. In: Bhattacharya, A., McGlothlin, J. (Eds.), Occupational Ergonomics – Theory and Application. Marcel Dekker, Inc, New York, pp. 545–567.

Marras, W.S., Lavender, S.A., Leurgans, S.E., Fathallah, F.A., Ferguson, S.A., 1995. Biomechanical risk factors for occupational related low back disorders. Ergonomics 38 (2), 377–410.

Mital, A., Kromodihardjo, S., 1986. Kinetic analysis of manual lifting activities: Part 2, biochemical analysis of task variables. International journal of Industrial Ergonomics 1, 91–101.

Mital, A., Nicholson, A.S., Ayoub, M.M., 1993. A Guide to Manual Materials Handling. Taylor and Francis, London, England.

NIOSH, 1981. Work practices guide for manual lifting. NIOSH publication No. 81–122, U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia.

Schneider, S., Susi, P., 1994. Ergonomics and construction: a review of potential hazards in new building construction. American Industrial Hygiene Association Journal 55 (7), 635–649.

The University of Michigan, 1995. 3D Static Strength Predication Program, Ver. 2.0, User's Manual, The University of Michigan, Center for Ergonomics, Ann Arbor, Michigan.

Warren, J., Bhattacharya, A., Lemasters, G., Applegate, H., Stinson, R., 1994. Focus groups: an aid for ergonomics assessment of carpentry tasks. American Industrial Hygiene Conference and Exposition, Anaheim.