Work 60 (2018) 661–671
DOI:10.3233/WOR-182773
IOS Press

Characterization of load reduction while lifting drywall using an unpowered drywall lifting device

Mark Eilertsen[1], Andrew Merryweather and Shad Roundy*
Department of Mechanical Engineering, University of Utah, Salt Lake City, UT, USA

Received 17 May 2017
Accepted 17 October 2017

Abstract.
BACKGROUND: Drywall installation has an injury rate four times that of the construction industry average. Workers are exposed to hazards related to slips, falls, and falling objects, in addition to the large and awkward loads they must carry. Drywall sheets can weigh more than 100 lb. and contribute to disabling musculoskeletal injuries of the shoulders and back.
OBJECTIVE: In this study, an unpowered lift assist device was developed to manage the load of a drywall sheet during the installation process.
METHODS: In order to measure the effect of the lift assist device, a laboratory study with 10 healthy male participants performing two lifts, lifting from ground to erect and lifting from erect to ceiling, with and without the help of the device, was performed. These lifts were chosen to simulate a drywall installer's frequent lifting motions. Participants were fitted with electromyography (EMG) on the *erector spinae, latissimus dorsi, rectus abdominus, and external oblique* muscles to measure activation. Mean, peak, and effort data for the lifting exercises were extracted and compared to the unassisted lift.
RESULTS: The lift assist device resulted in a reduction in mean EMG signal of 69% average over both lifts and muscle groups. Peak EMG and effort (i.e., area under the curve) were reduced by 78% and 75%, respectively.
CONCLUSIONS: These data demonstrate the effectiveness of the device in reducing compressive back loads during drywall installation, which warrants future development.

Keywords: Drywall lifting, back injury, occupational injuries, construction, back pain

1. Introduction

Undeveloped worksites, exposure to the elements, poor lighting, heavy and powerful equipment, among other factors, make construction trades some of the most dangerous occupations in the world [1]. The fourth most dangerous occupation in the construction industry is *drywall* installation [2]. Drywall is the flat panel that forms the surface of the interior walls of a residential or commercial building. An estimated 97% of new homes are constructed using drywall [3] and worldwide, the drywall industry represents a $48 billion market employing more than 88,000 workers [4].

At the construction site, workers will place the drywall in a vertical stack against a framing wall or in a horizontal stack on the floor. The sheets, once stacked in the house/building, are cut to the length and height needed to cover the framing. The sheet is lifted into place by the installer and attached to the framing using nails or screws. Figure 1 shows an example of a person lifting a sheet of drywall in a laboratory setting in the manner that it is typically lifted during framing and hanging.

[1]Current affiliation is United States Air Force.

*Address for correspondence: Shad Roundy, Department of Mechanical Engineering, University of Utah, 1495 E 100 S (1550 MEK), Salt Lake City, UT 84112, USA. Tel.: +1 801 581 4304; Fax: +1 801 585 9826; E-mail: shad.roundy@utah.edu.

Fig. 1. Installer lifting drywall into place on a wall.

There are numerous environmental factors and job tasks that the Occupational Safety and Health Administration (OSHA) cites as potential risks in material handling and most of these are common to the drywall trade. One of the dangers cited by OSHA is low visibility, as it increases the chance of slips, trips, and falls [5]. Drywall workers are exposed to slips and falls at both ground and elevated levels in addition to being exposed to falling materials and tools [6]. Several other dangers in material handling that are relevant for drywall workers are awkward positions (bending, lifting, and carrying), including inadequate handholds that make holding, lifting and carrying objects more awkward, and heavy weight (50 lbs. or more) [5]. Sheets of drywall are always 4 ft. tall, but range in length from 8 ft. to as much as 16 ft. Sheet thickness can vary from 1/4 in. to 5/8 in. in the U.S. market. Thus, the size of drywall sheets can make them difficult to handle, which often results in drywall workers lifting heavy loads in awkward positions on ladders and scaffolding [7]. Further, although the weight of a drywall sheet varies from 30 lbs. to 200 lbs., the typical 4 ft. × 8 ft. × 1/2 in. sheet weighs approximately 50 lbs. The weight of the drywall panel poses a severe threat to the safety and musculoskeletal health of drywall workers during the installation process [8]. On average, the weight of the drywall panel exceeds recommended loading limits for the back [7, 8]. According to the NIOSH Recommended Weight Limit (RWL), the load constant for which is safe for 75% of females and 90% of males is 51 lbs. [9]. The standard drywall sheet is already at this limit. When considering the combination of large loads and awkward positions, the RWL multiplier factors will easily cause the drywall to exceed RWL according to the NIOSH lifting index. In addition to weight, awkward positions, and falls, overexertion also increases a drywall worker's risk for musculoskeletal disorders (MSDs) [5]. High-frequency and long-duration lifting (holding items until installed and repetitive exertions) lead to overexertion. One study found that 28. 1% of injuries in drywall workers was due to overexertion [10].

The preponderance of data point to the lifting, carrying, and attaching of drywall as the most hazardous phases of the installation process [10, 11]. According to a study of 20 years of workers compensation claims in the state of Washington by Shoenfisch et al. [12], the rates of back injuries among drywall installers decreased by roughly 70% between 1988 and 2008. However, overexertion back injuries still make a large proportion of overall injuries (17.1%). Efforts have been made to address the risks associated with drywall installation through proper training, however, many workers are set in their ways and change is a slow process [13]. Drywall size is increasing in order to minimize installation time and finishing effort. This increase may present an additional injury risk moving forward.

For more than 50 years, other industries in manufacturing that face similar problems with heavy weights and awkward objects have used lift-assisting devices. While the human user must interface with the object being moved or the machine doing the lifting, the machine bears a majority of the weight and receives input from the user. An example of this application is glass panels being lifted via cable support arms or mobile-base cranes. All these devices are useful in their intended settings, but they often require heavy, fixed bases. Even if the bases are not fixed, they are usually heavy and large, which makes moving through a residential or office building with confined spaces slow and prone to collisions or accidents. Therefore, a new class of lifting device is needed to support the drywall installation industry. The device should have the following characteristics:

- Easily portable in the construction environment by one drywall worker;

- Limits floor loading to 30 lbs. per square foot to meet design loads [14];
- Limits power consumption to generator capabilities;
- Able to reach the entire working envelope (from sheets laying on the ground to a 12-ft. ceiling);
- Reduces loads placed on drywall worker's musculoskeletal frame, specifically the *erector spinae* muscles.

Although some previous studies have attempted to build models [15] or assess sampled positions during installation [8] to estimate or predict the loading on the a drywall worker's back, to our knowledge, no one has actually measured muscle activation during drywall installation. Pan and Chiou [8] estimated that a user lifting a 60-lb sheet using the lower lift described above would experience a back compressive load of 915 lb. The NIOSH [16] recommended working level for the spine is 770 lbs. [17]. Thus, a 15% reduction of stress in the user's back would place the stress within the recommended spinal compression force. In order to determine if our device reduced spinal compression forces by at least this amount, we observed and compared the EMG muscle activation during unassisted and assisted lifting. While the EMG signal magnitudes are not a direct measurement of the spinal disk compression force, they do have a strong correlation [18]. Changes in muscle activation while using assistive devices are often used to evaluate the efficacy of an intervention and to quantify risk during lifting. The goal of this work is to quantify the reduction in loads on the lower back resulting from use of an unpowered lift assist device that was designed and built by the authors.

2. Methods

2.1. Procedures

We developed a lift assist device for drywall installers based on a polar robot configuration (see Fig. 2). The base consists of a tripod for stability and wheels for mobility that can be locked during operation for stability. At the top of the base is a two-axis joint that allows for yaw and pitch motions. There is also a telescoping arm that will extend far enough to reach walls and ceilings throughout the working environment without having to relocate the device. At the distal end of the arm is a head that allows for three degrees of freedom to pick up and place a sheet of drywall in three-dimensional space (i.e., roll, pitch and yaw). At the back end of the arm are weights, which are used to counterbalance the head and drywall.

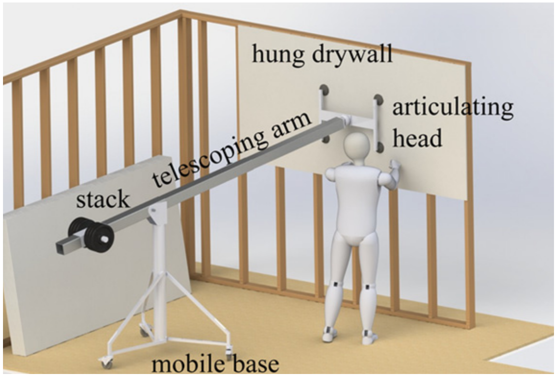

Fig. 2. Concept for drywall lifting device.

Fig. 3. CAD image of the lift assist device.

For the purposes of this study a few simplifications were made in the design to reduce fabrication complexity while still enabling the quantification of back loads with and without the device. First, the arm does not telescope. Second, the mechanism at the distal end allows for two (rotation about pitch and yaw axes) rather than three degrees of freedom. Finally, the drywall is bolted to the device rather than using suction cups as would be the case in a real-world device (see Fig. 3).

The torque at the pitch axis of the arm is the parameter of primary concern because lifting the sheet requires either a torque at this joint or a force at some point on the arm. In the present configuration, the force is created by the device's user lifting up on the sheet of drywall. The torque required at the pitch axis is given by:

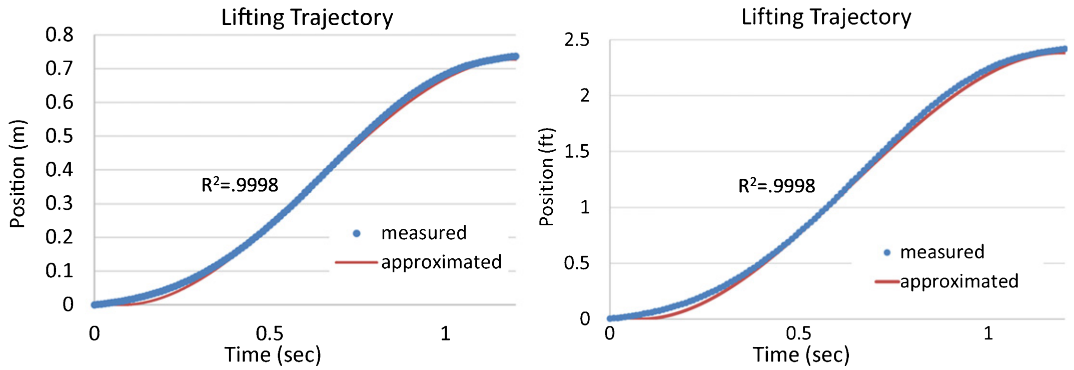

Fig. 4. Drywall sheet lifting trajectory.

$$\tau = I\alpha + b\omega + mgr \tag{1}$$

where

I = combined moment of inertia for the arm, counter weights, head, and drywall;

α = angular acceleration of the arm;

b = viscous damping coefficient for the bearing;

ω = rotational speed of the arm;

m = combined mass of the arm, counterweights, head, and drywall; and

r = distance from pitch axis to the center of mass of the arm assembly.

Equation (1) assumes the sheet of drywall remains in a relatively vertical orientation during the lift. Upon inspection, the torsional damping force due to the bearing is much lower than the inertial effects of the arm. In addition, a basic calculation, Beardmore [19], was used to estimate the friction torque for a single-row ball bearing. This calculation indicates that the friction torque would be 0.0012 N-m, orders of magnitude below the 85 N-m due to the inertial load. For this reason, we assume that the damping term in Equation (1) is sufficiently small with respect to the inertial term that it can be ignored. The arm position and counterweights are adjusted until the arm is virtually balanced on the pitch axis, which eliminates the third term, leaving only the first term in Equation (1), as shown in Equation (2).

$$\tau = I\alpha \tag{2}$$

This torque can be converted into a force that the user would apply at the drywall sheet. Because the torque depends on angular acceleration, it is necessary to determine the motion of a sheet during a typical lifting cycle, which we did by tracking the vertical position of a sheet of drywall (center of mass)

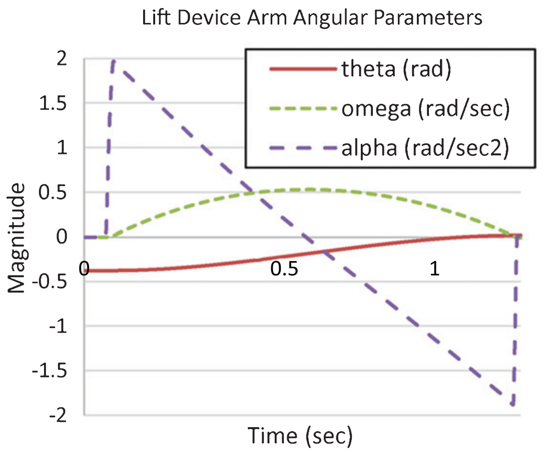

Fig. 5. Lift device arm angular position parameters during lifting cycle.

during a lift from ground level to a carrying position. This lift is typical of picking up a sheet from a stack on the ground to a carrying position. Figure 4 shows this profile with respect to time. The motion of the sheet can also be approximated by Equation (3) and is also represented in Fig. 4.

$$y_1(t) = -1.0577x^3 + 2.013x^2 - 0.2971x + 0.0114 \tag{3}$$

Figure 5 shows the angular position, velocity, and acceleration for the pitch angle of the lift device arm that produces the trajectory in Fig. 4. The angle of the arm (θ) is negative at the beginning of the lift because the arm pivot is above the center of the sheet when the sheet is resting on the ground. The force expected in the user's hand during the assisted lifting cycle is determined using the second derivative

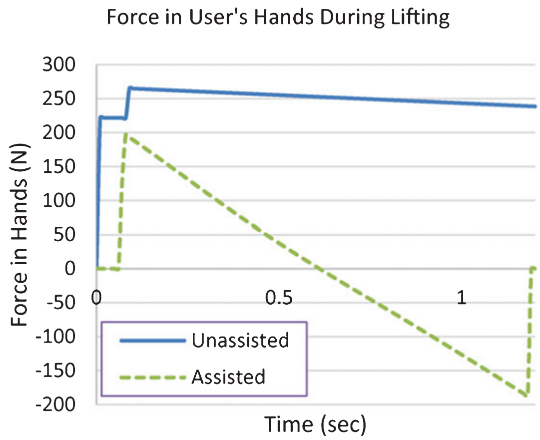

Fig. 6. Force in user's hands during lifting cycle.

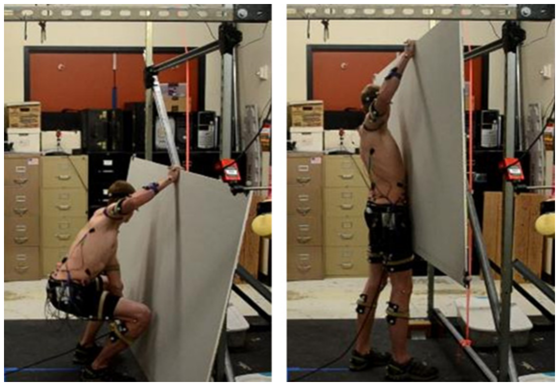

Fig. 7. Unassisted lifting from the ground.

of Equation 3 (acceleration) as input to calculate the force. The force that would be expected in a user's hand during an unassisted lift is determined by the equation ($F = ma + mg$). Figure 6 shows the expected force in a user's hand during both an assisted and an unassisted lifting cycle. During the unassisted lift, the force in the user's hands is, on average, 250 N. During the assisted lift, the maximum load in the user's hands is 196 N, however, the load decreases to zero during the first half of the lift and then goes negative during the second half. It is expected that the user will experience, on average, a 63% reduction in force during the first half of the lift. During the second half of the lift, when the mass is decelerating, the user will realize a negative force from the assisted lift. This negative force results from the user decelerating the rotating mass. While the deceleration is of equal magnitude to the forces experienced by the user during first phase of the assisted lift, the user is now pulling down on the sheet. This effort results in the load being shifted primarily to the abdominal muscles. While the abdominal muscles do contribute to spinal compressive loads, they have a significantly lower contribution.

In this study, we are interested in evaluating the effect of the lift assist device on compressive loads on the spine. A well-established and widely accepted model of the compressive loads on the back was developed by Schultz [20, 21]. In this model, compressive loads are a function of the erector spinae muscle force, abdominal wall force, rectus abdominus force, and left and right oblique muscles forces. Although the muscle forces cannot be measured directly, their values can be estimated using surface EMG sensors [22]. Each muscle must be analyzed to find the relationship between the signal and force. Once this relationship is known, we can demonstrate that a decrease in the relative magnitude of the EMG signal in a muscle will result in the relative muscle force having been decreased by the same percentage. If we can demonstrate that the EMG signal for all muscles that contribute to the spinal compressive load decreases, we make a similar claim that the compressive load on the spine has been reduced by a similar amount.

Effort, which is the integral of force exerted over time is also important because effort correlates to fatigue throughout the day. If the effort is reduced for each lift, then a person could conceivably work longer. The integrated EMG signal is a commonly used measure for mean force of an activity [23] and a proxy for energy [24]. In the context of this research, we use integrated EMG (i.e. ea under the EMG curve) as a proxy for effort. Although this measure of effort is not the traditional measure, as EMG signal correlates to force, the present definition is analogous.

2.2. Data collection

Two types of lifts were studied during this experiment. The first involved lifting a sheet of drywall from the floor to an erect-carrying position (approximately 0.75 m). This motion is the lift most commonly observed in the residential market [8]. During the unassisted lift, the erect-carrying position (see Fig. 7) is achieved when the legs are in a full standing position, one arm is in a dead hang holding the bottom of the sheet, and the other hand is holding the top of the sheet.

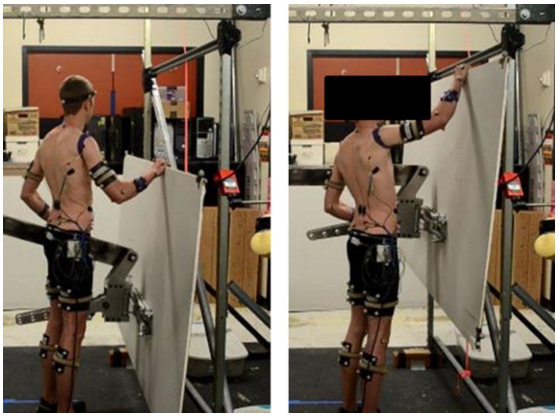

Fig. 8. Assisted lift from the ground.

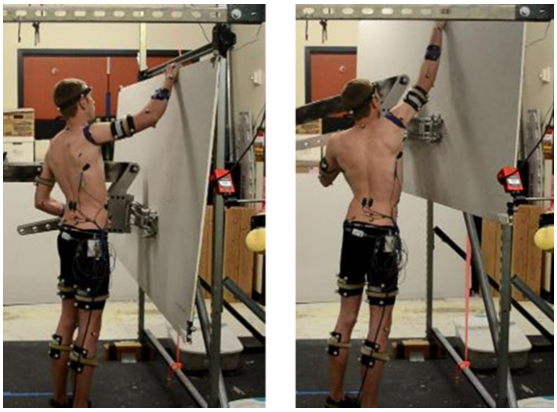

Fig. 10. Assisted lift to the ceiling.

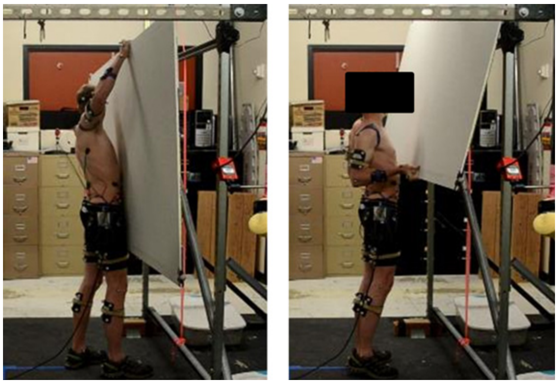

Fig. 9. Unassisted lift to the ceiling.

During the assisted lift, the participant was not required to squat down to grab the bottom of the sheet before lifting (see Fig. 8). Because the device supported a majority of the load, the participant was only required to grab the machine or the sheet in a manner that was comfortable for him. This lift typically involved the participant remaining standing and guiding the sheet up, with one hand on the device arm and another on the sheet to maintain orientation.

The second lift began in the lifted position previously described. The participant then lifted the sheet so that the top of the sheet reached 8 ft., which is the typical height of a residential ceiling. This lift was performed first as an unassisted lift (see Fig. 9), and then repeated as an assisted lift using the lift assist device to counterbalance the weight of the drywall (see Fig. 10). With two lower motions and two upper motions, there were a total of four lifting sequences. Each of these sequences (lower-assisted, lower-unassisted, upper-assisted, upper-unassisted) was repeated four times, resulting in a total of 16 lifts that were conducted by each participant. Each participant was assigned a number and a random order was followed for each of the four lift sequences. These lifting motions were chosen because they are the most common positions and most likely to cause injury [8].

Eight Bagnoli surface electrodes (Delsys Inc., Natick, MA) were affixed to each participant (see Figs. 7–10) on the muscles listed in Table 2. These muscles were chosen for the major contributions they make during the lifting cycle. The sensors were attached by an experienced technician according to [25–27]. Double-sided adhesive tape as well as coflex wrap was used to hold the surface electrodes in place. A grounding probe was also placed on the participant's acromion.

All of the sensors and probes were attached to a BNC-2111 connector block (National Instruments, Austin, TX) from which lines fed the data into the computer via a NI 6210 data acquisition system (National Instruments, Austin, TX). The signal was sampled at a rate of 10 kHz. The data were processed in the following order:

1. Low pass filtered at 450 Hz.
2. Bias removed to baseline signal to zero.
3. Full wave rectification.
4. Time shifted so that all lifts started at time ($t = 0$).
5. Averaged all lifts for a participant of the same type (i.e., upper lift unassisted).
6. Extract data (peak, mean, standard deviation, total effort).

We did not explicitly analyze the difference between left and right side muscles in this study. We do note that although for a given subject EMG signals

Table 1
Participant Demographics

Variables	Mean	*SD*	Range
Age	32.3	5.8	24–43
Height (in.)	71.2	2.1	68–75
Weight (lbs)	173.5	23.5	134–210

Table 2
EMG Muscle Groups

Right and left *erector spinae*
Right and left *latissimus dorsi*
Right and left *rectus abdominus*
Right and left *external oblique*

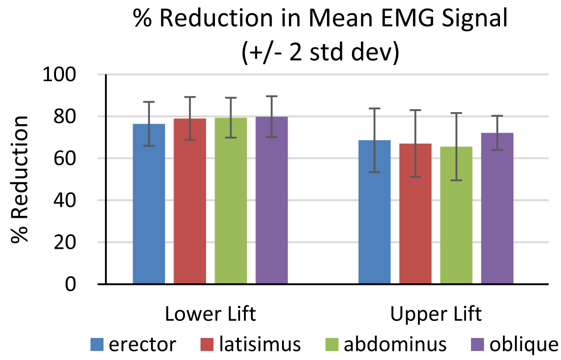

Fig. 12. Percent reduction in the mean EMG value.

for left and right sides do differ, they do not differ in the same way between subjects. For some subjects the right side will be higher, while for others, the left side will be higher. For the purposes of this study, we only analyze the average of all EMG readings for a given muscle group.

In addition to the EMG sensors, the participant was fitted with infrared (IR) markers to allow for the capture of 3D motion capture cameras installed in the lab. Although these motion capture data were not factored into this study, they could be used at a later date for a more thorough analysis.

3. Results

A convenience sample of 10 participants was solicited to complete this study. Although experience installing drywall was preferred, this was not an exclusion criterion given that the device is intended to be used by both professionals and novices. Inclusion criteria included gender (men), age (18 to 45), and no history of back injuries. Table 1 contains a summary of the demographics of the participants.

An example of the output data for the *erector spinae* for a single lift is shown in Fig. 11. This particular data set is for the lower lift performed by Participant 2. The signal indicated in the plot is the average of the left and right muscles, as well as the four repetitions of the same lift. This plot is characteristic of the signals generated by all participants and for all lifts. Across all the unassisted lifts a spike in muscle exertion at the start of the lift was recorded, likely due to the acceleration of the drywall. This spike is followed by a reduction in exertion, but is always greater than for the assisted lift. The assisted lift recorded fewer spikes in the EMG signal and a consistently low level throughout the lift.

3.1. Mean EMG signal

Across all muscle groups in both the upper and lower lifts, there was an average 69% reduction in mean EMG signal during the lifting cycle. Average reductions were greater for the lower lift than for the upper lift (78% vs. 68%), which is to be expected, given the significant posture change during the lower lift. See Fig. 12.

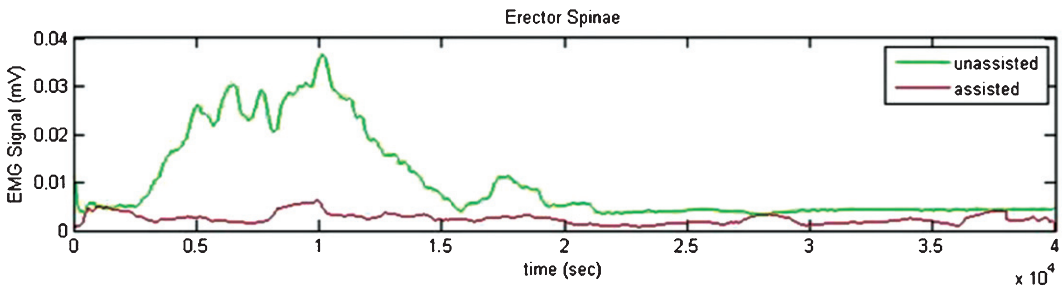

Fig. 11. Sample output data for a lower lift. EMG signals from assisted lift are in red. EMG signals from unassisted lift are in green.

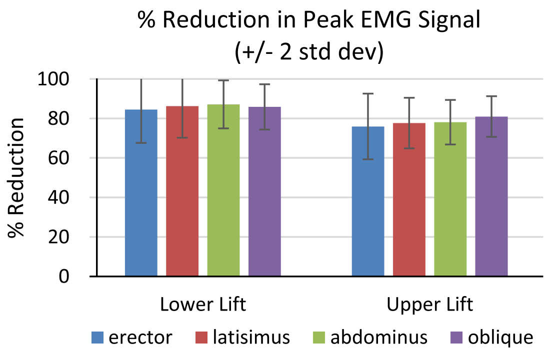

Fig. 13. Percent reduction in peak EMG value.

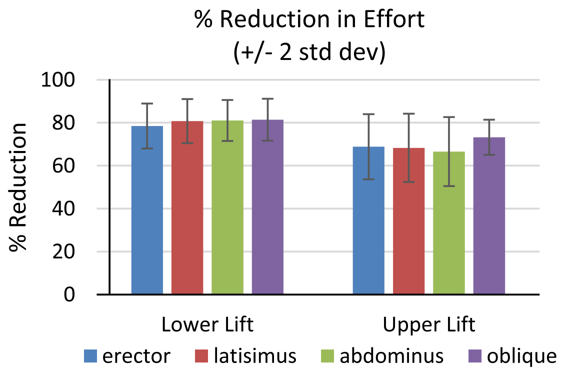

Fig. 14. Percent reduction in effort.

3.2. Peak EMG signal

Across all muscle groups in both the upper and lower lifts, there was an average 78% reduction in peak EMG signal during the lifting cycle. Average reductions were greater for the lower lift than for the upper lift (86% vs. 78%). See Fig. 13.

3.3. Effort

Across all muscle groups in both the upper and lower lifts, there was an average of 75% reduction in effort during the lifting cycle. Average reductions were greater for the lower lift than for the upper lift (80% vs. 69%). See Fig. 14 for details.

Across all lifts and all muscle groups, the average reduction in mean EMG signal was 69%, which is close to what was predicted (63%). Factors such as posture, location of the load, and EMG-to-muscle force ratios all play a role in the correlation. However, there is a strong correlation between hand loads and EMG signals and there was sufficient reduction in the EMG signals to suggest that the assisted lifting

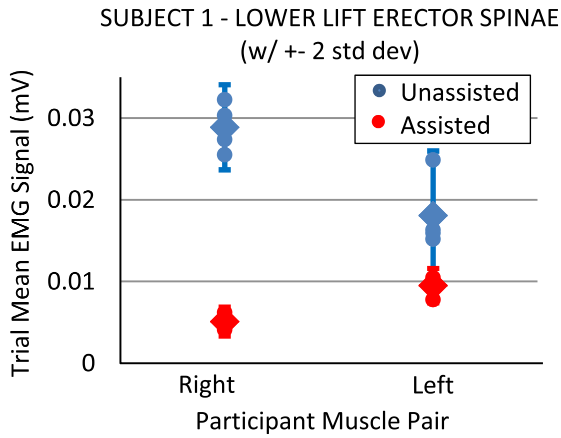

Fig. 15. Subject 1 data spread comparison.

device would significantly reduce the back compressive loads and effort required by the participants during the lifting cycle. This evidence is reinforced by verbal feedback and observations of the participants during the testing.

3.4. Individual muscle data

Each of the muscle data values was plotted to demonstrate whether a relationship between the left and right muscles was present, as well as to represent the significance of the reduction in signal due to the lift assist device. The chart in Fig. 15 shows the mean EMG values for the *erector spinae* muscles during the lower lift by Participant 1. It is representative of a majority of the signals obtained. There are two common characteristics among all participants. First, because the body is not symmetric during the lift, one of the muscles exerts more effort than another. Second, the values for the unassisted lift are higher than those of the assisted lift, with two standard deviations rarely overlapping. Figure 16 shows these data for all 10 study participants.

A *t*-test (95% confidence) was performed to compare the mean, peak, and effort values for both the left and right muscle signals individually. For example, the mean values for Participant 1's right *erector spinae* during the lower unassisted lift (four data points) were compared to those of Participant 1's assisted lift (four data points). In a majority of the cases, the *t*-test showed a significant decrease in muscle activation ($p < 0.05$).

Effort made by the *erector spinae* muscle was significantly reduced in 100% of the cases. Effort reduction in the *rectus abdominus* muscle was

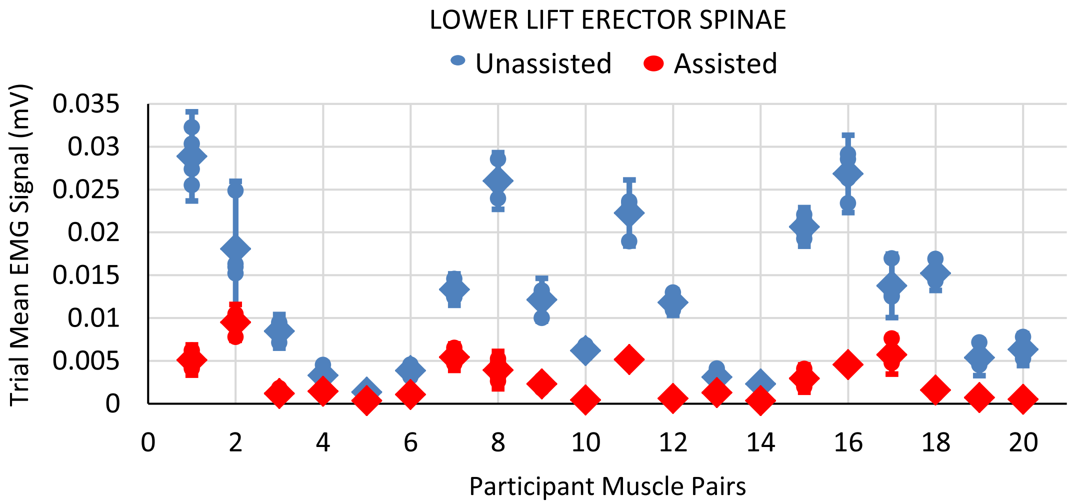

Fig. 16. Mean values and spread (+/– 2 standard deviations) for the *erector spinae* muscle for the lower lift. Each side shown for all 10 subjects. So, muscle pairs 1 and 2 are the right and left muscles of Participant 1.

significant in an average of 72% of cases, which was the lowest of the four muscle groups. This disparity was expected because the lifting motion mostly uses the *erector spinae*, *latissimus dorsi*, and *oblique* muscles due to asymmetry. These data further validate that the lifting device significantly reduces back compression, which conforms with observations made during actual testing.

3.5. Study limitations

The limitations of this study were the small sample size. A more robust number of participants with a wider range in age, height, weight, and experience would provide results more generalizable to the drywall worker population. Another limitation was that the study took place in a lab as opposed to a real-world work setting. Future studies may wish to use the device on drywall workers operating in actual construction environments and under the deadlines and space constraints likely found in a real-world work environment. In addition, it would be beneficial to test the device with a working telescope arm in order to determine what reductions in effort might be found when attaching drywall sheets to the ceiling; fabrication costs made the telescoping arm unavailable for the current study.

3.6. Study discussion

The study results indicate that the unpowered lift assist device significantly reduces muscle activation, measured by peak EMG signal, and muscle effort, measured by integrated EMG signal, during motions common to drywall installation. This reduction occurs for all muscle groups measured: *erector spinae, latissimus dorsi, abdominus rectus,* and *oblique*. *T*-tests indicate a significant reduction ($p < 0.05$) in most cases (10 subjects), however, given the small sample number (4 lifts per person), caution regarding statistical significance is warranted. Still, given the very large average reductions in mean and peak EMG signal (69–86%), it is reasonable to conclude that the lift assist device has a real and practical benefit.

Although the sample size was small, it was representative of the majority of workers in this trade and an adequate number of data points—160—were gathered to offset the small sample size. The strengths of this study include the use of two lifts, upper and lower, each of which was done assisted and unassisted. This aspect of the study design addressed the installation of drywall on both upper parts of the wall and lower parts of the wall—a setup that reflects what drywall workers encounter on the job. The use of 8 electrodes was another strength as it ensured all major muscle groups activated during lifting were being measured.

As shown in Figs. 15 and 16, a large discrepancy exists between both the muscle activation and the reduction in muscle activation between right and left sides of the body. However, for some subjects the right side has a higher activation and for some subjects the left side has a higher activation. We did not specifically study the potential causes for the left-right side differences. This would be an appropriate subject for a follow up study.

Another interesting result is the larger reduction in muscle activation on the lower lift compared to the upper lift. The lower lift does require the user to squat down during the initial part of the unassisted lift. Because the loads at the users' hands are so much smaller during the assisted lift, most users did not squat at all during the lower lift (see Figs. 7 and 8). The upper lift does not require a squat in either case, assisted or unassisted. It is possible that this squatting / no squatting motion during the unassisted / assisted lower lift could account for the larger reductions in muscle activation. A biomechanical analysis could shed further light on the larger reduction during the lower lift.

As indicated in Fig. 16, there was a very large user to user variation in muscle activation during the unassisted lift. The variation as well as the magnitude in EMG signals reduced significantly for the assisted lift. The large variation during the unassisted lift is somewhat of a surprise and would also benefit from a future biomechanical analysis.

The unpowered lift assist device does appear to perform the primary function intended, which was to reduce loads, and therefore risk of injury, among drywall installers. However, the current design has several shortcomings which could be improved in a future design. Specifically, the following functionality would be beneficial:

- telescoping arm to increase the work envelope and limit the need for the device to traverse on wheels during operation;
- moveable counterbalance weights to adjust for the telescoping arm and different size sheets of drywall;
- feedback control on the counterbalance to actively provide balancing and user effort during lifting;
- suction cups to attach drywall to the device quickly;
- brake on pitch axis lock position during detaching of suction cups (before counterbalance has had time to adjust);
- more degrees of freedom to the head mechanism to allow installation on ceiling or in a vertical orientation, as well as picking up sheets from a horizontal stack.

4. Conclusions

This study serves to demonstrate that unpowered tools can be adapted to reduce worker injuries in the drywall industry. Using an unpowered lifting device similar to those found in other industries can reduce the mean EMG values measured in drywall workers' backs by 69%. This large reduction in muscle activity suggests that a significant reduction in compressive loads would also be observed. Lowered compressive forces reduce the risk of lifting related injuries and could prolong working years and productivity among drywall workers. The unpowered lifting device developed and tested in this study has the potential to decrease costs associated with worker's compensation and disability by lowering injury rates in this trade. Although considerable development is needed before this device can be successfully deployed in the construction environment, this device, as demonstrated, represents a positive step in addressing the serious health risks associated with handling heavy, awkward loads.

Conflict of interest

None to report.

References

[1] U.S. Department of Labor, Bureau of Labor Statistics (BLS). Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data [Internet]. Washington DC: US Bureau of Labor Statistics | OCWC/OSH; 2015 [updated 2017 December 19, cited 2018 January 25]. Available from: https://www.bls.gov/iif/oshcfoi1.htm#2015

[2] Hsiao H, Stanevich RL. Injuries and ergonomic applications in construction. In: Bhattacharya A, McGlothlin JD, editors. Occupational ergonomics: Theory and applications. New York: Marcel Dekker; 1996. pp. 545-68.

[3] Gypsum Association [Internet]. Silver Springs MD: Gypsum Association; 2016 [cited 2018 January 25]. Available from https://www.gypsum.org/about/building-the-economy/

[4] U.S. Department of Labor, Bureau of Labor Statistics (BLS). Occupational Employment and Wages, May 2016 [Internet]. Washington DC: US Bureau of Labor Statistics | Division of Occupational Employment Statistics; 2016 [updated 2017 March 31, cited 2018 January 25]. Available from: http://www.bls.gov/oes/current/oes472081.htm

[5] Occupational Safety & health Administration. Ergonomics eTool: Solutions for Electrical Contractors [Internet]. Washington DC: US Department of Labor. [cited 2018 January 25]. Available from: https://www.osha.gov/SLTC/etools/electricalcontractors/materials/heavy.html

[6] Chiou SS, Pan CS, Keane P. Traumatic injury among drywall installers, 1992 to 1995. J Occup Environ Med. 2000;42(11):1101-8.
[7] Pan CS, Chiou SS. Analysis of biomechanical stresses during drywall lifting. Int J Ind Ergon. 1999;23(5):505-11.
[8] Dasgupta PS, Fulmer S, Jing X, Punnett L, Kuhn S, Buchholz B. Assessing the ergonomic exposures for drywall workers. Int J Ind Ergon. 2014;44(2):307-15.
[9] Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics. 1993;36(7):749-76.
[10] Lipscomb HJ, D.J., Gaal JS, Cameron W, McDougall V, Work related injuries in drywall installers. Appl Occup Environ Hyg. 2000;15(10):794-802.
[11] Lipscomb HJ, Dement JM, Gaal JS, Cameron W, McDougall V. Work-related injuries in drywall installation. Appl Occup Environ Hyg. 2000;15(10):794-802.
[12] Schoenfisch AL, Lipscomb HJ, Marshall SW, Casteel C, Richardson DB, Brookhart MA, Cameron W. Declining rates of work-related overexertion back injuries among union drywall installers in Washington State, 1989–2008: Improved work safety or shifting of care? Am J Ind Med. 2014;57(2):184-94.
[13] De Jong AM, Vink P. The adoption of technological innovations for glaziers; evaluation of a participatory ergonomics approach. Int J Ind Ergon. 2000;26(1):39-46.
[14] American Wood Council (US). Span Tables for Joists and Rafters, 2015 Edition. Leesburg (VA): American Wood Council; 2015. pp. 52. American Softwood Lumber Standard (PS 20-15) Sizes.
[15] Yuan L, Buchholz B, Punnett L, Kriebel D. Estimation of muscle contraction forces and joint reaction forces at the low back and shoulder during drywall installation. In Proc Hum Factors Ergon Soc Annu Meet. 2007 Oct (Vol. 51, No. 15, pp. 952-956). Sage CA: Los Angeles, CA: SAGE Publications.
[16] U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health (NIOSH) (US). Work Practices Guide for Manual Lifting. Cincinnati (OH); March 1981; pp. 183. NIOSH Pub. 81-122
[17] Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics. 1993;36(7):749-76.
[18] Hughes RE, Chaffin DB. The effect of strict muscle stress limits on abdominal muscle force predictions for combined torsion and extension loadings. J Biomech. 1995;28(5):527-33.
[19] Beardmore, R. Roller bearing friction [Internet]. Place unknown: Roymechx; 2010 [updated 2013 Jan 17, cited 2018 Jan 25]. Available from: http://www.roymech.co.uk/Useful_Tables/Tribology/Bearing%20Friction.html
[20] Schultz A, Andersson G, Ortengren R, Haderspeck K, Nachemson A. Loads on the lumbar spine. Validation of a biomechanical analysis by measurements of intradiscal pressures and myoelectric signals. JBJS. 1982;64(5):713-20.
[21] Schultz AB, Andersson GB. Analysis of loads on the lumbar spine. Spine. 1981;6(1):76-82.
[22] Liu MM, Herzog W, Savelberg HH. Dynamic muscle force predictions from EMG: An artificial neural network approach. J Electromyogr Kinesiol. 1999;9(6):391-400.
[23] Bigland-Ritchie BR, Woods JJ. Integrated EMG and oxygen uptake during dynamic contractions of human muscles. J Appl Physiol (1985). 1974;36(4):475-9.
[24] Bigland-Ritchie B, Donovan EF, Roussos CS. Conduction velocity and EMG power spectrum changes in fatigue of sustained maximal efforts. J Appl Physiol (1985). 1981;51(5):1300-5.
[25] Konrad P. The abc of emg. A practical introduction to kinesiological electromyography [Internet]. Scottsdale AZ: Noraxon; 2005 [cited 2018 Jan 25]. pp. 61. Available from: http://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf
[26] Kramer DM, Bigelow PL, Carlan N, Wells RP, Garritano E, Vi P, Plawinski M. Searching for needles in a haystack: Identifying innovations to prevent MSDs in the construction sector. Appl Ergon. 2010;41(4):577-84.
[27] Merletti R, Di Torino P. Standards for reporting EMG data. J Electromyogr Kinesiol. 1999;9(1):3-4.