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Does drywall installers' innovative idea reduce the ergonomic exposures of ceiling installation: A field case study

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ABSTRACT

Objective: The study was conducted to assess an intervention suggested by the workers to reduce the physical or ergonomic exposures of the drywall installation task.
Methods: The drywall installers were asked to brainstorm on innovative ideas that could reduce their ergonomic exposures during the drywall installation work. The workers proposed the idea of using a 'deadman' (narrow panel piece) to hold the panels to the ceiling while installing them. The researcher collected quantitative exposure data (PATH, 3DSSPP) at the baseline and intervention phases and compared the phases to find out any change in the exposure while using the 'deadman'.
Results: Results showed that ergonomic exposures (such as overhead arm and awkward trunk postures and heavy load handling) were reduced at the intervention phase while using the 'deadman' with an electrically operated lift.
Conclusion: The concept of the 'deadman', which was shown to help reduce musculoskeletal exposures during ceiling installation, can be used to fabricate a permanent ergonomic tool to support the ceiling drywall panel.

1. Introduction

Due to the direct and indirect costs associated with construction injuries, workers' safety has become a prime concern in the construction industry over the last few decades. According to the U.S. Bureau of Labor Statistics (BLS), around 7.7 million construction workers were employed in the USA in 2012. Among them, 129,600 workers worked as drywall and ceiling tile installers (BLS). In the same year, there were around 2.5 million drywall and ceiling tile jobs in the USA. The National employment matrix has projected that there will be around 166,900 (28% increase from 2010) drywall workers working in the USA in the year 2020 (Bureau of Labor Statistics, 2013).

Due to the physically demanding nature of the drywall installation job including the requirement to handle (raise, hold and install) up to 110 lb drywall panels (Yuan et al., 2007) while being on a ladder, the workers health are threatened with risk of musculoskeletal disorders (MSDs) affecting the back, shoulder, neck, wrist and hand (Chiou et al., 2000; Lemasters et al., 1998; Lipscomb et al., 2003, 2008, 1997). Dasgupta et al. (2014) assessed ergonomic exposures in drywall carpentry and found considerable exposure related to the drywall installation task. The main hazardous activity observed in this task was lifting the drywall panels to the ceiling and holding them up against the ceiling frame with both arms in an overhead posture.

Workers themselves are aware of this issue. Pan et al. (1999) surveyed 60 carpenters about their perception of hazardous tasks during drywall panel handling. The workers perceived that lifting and/or holding a drywall panel in an overhead position caused the maximum physical stress.

Hess et al., 2010a, implemented carrying tools to reduce the low back force of the installers. Although the risks of drywall installation have been identified by this group of researchers (Dasgupta et al., 2014) to date no study, except this piece of research, has attempted to implement an intervention in order to reduce the

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exposures for ceiling panel installation for drywall workers.

Workers are excellent sources for feedback on the implementation of new tools or techniques as a solution to their workplace hazards (Hess et al., 2004; Kramer et al., 2009; Vander Molen et al., 2005a,b). Focus groups give the workers an opportunity to collectively discuss advantages or disadvantages of tools and techniques, and to brainstorm solutions to problems. It is not uncommon to have valuable ideas from workers during informal meetings at the construction sector and these have been documented previously by researchers (Buchholz and Moir, 1996; Hess et al., 2004; De Jong and Vink, 2000; Moir et al., 1997; Moir and Azaroff, 2007; Vander Molen et al., 2005 a,b). Studies that have engaged construction workers in focus groups or meetings to consider their ideas and suggestions in order to develop useful solutions showed successful reduction in musculoskeletal or physical exposures (De Jong and Vink, 2002; Hess et al., 2004; Vander Molen et al., 2005a,b; Kramer et al., 2009; Kramer et al., 2010; Williams et al., 2010; Hess et al., 2010b). Hence, engaging them in focus groups or participatory meetings to identify solutions to the existing issues of installation task was considered as a rational way to proceed towards an intervention.

The objective of this study was to engage the drywall installers in focus groups (participatory manner) in order to discuss innovative ways to reduce the ceiling installation exposures of the drywall installation task. It was hypothesized that the installers will be able to give feasible solutions that will reduce the physical exposures during drywall installation. Hence, in case, the workers' ideas were translated and implemented as an intervention, this study aimed to evaluate the efficacy of that intervention.

2. Methods

2.1. Study site and participant recruitment

The safety officer of a construction site (with whom the researcher had prior research experience) showed interest in the research objective and gave permission to conduct the research. He distributed flyers to the drywall installers on the research process and the incentive offered for participation at the site.

2.2. Introductory meeting on concept of 'Ergonomics'

The safety officer introduced the researcher to the workers, which provided an opportunity to be engaged in 'face to face' discussion. The researcher introduced the concept of ergonomics to the workers to enhance their knowledge in recognizing the exposures of the drywall installation task. The focus of the introductory meeting was to explain the workers about the musculoskeletal exposures of ceiling installation task in order to make them have ideas to reduce those exposures. Also, the researcher targeted this meeting to share possible discussion topics for the first focus group meeting. The proposed length of this meeting was 30 min.

2.3. Focus group meetings: innovation ideas

The workers were asked to participate together in three focus group meetings and to be as informative as possible. The topic of each meeting was developed based on workers' opinions from the previous meeting. They were asked to give feasible intervention ideas that would reduce concerns related to the drywall installation task. The focus group meetings were organized in the morning, 35 min prior to the start of work day. We aimed to include the same group of workers in all three meetings.

The topics of discussion at each meeting are detailed below.

2.3.1. Focus group meeting 1

A brief overview of the existing knowledge about exposures during drywall installation was given, focusing on published literature and prior focus groups carried out by this research team. The workers were then asked to utilize their knowledge to suggest a modification of any activity of the drywall installation task, which could potentially decrease strain on the neck, shoulders and back as compared to previous methods.

2.3.2. Focus group meeting 2

At the second meeting, workers were asked to brainstorm on ideas and propose ways to lift the panels to the ceiling that could decrease strain especially on the neck, shoulders and back.

2.3.3. Focus group meeting 3

The workers were asked to discuss the pros and cons of carrying out a chosen intervention for the drywall installation task. If one installer introduced a new idea, other installers were also encouraged to share their perception on the pros and cons of using it.

2.4. Informal meetings

During the course of the study, which was about 4 months, the installers were encouraged to share their opinions through informal conversations with the researcher, before or after the finish of their break time at the site.

2.5. Data collection and analysis

2.5.1. Exposure characterization

Quantitative exposure data were collected using PATH (Posture, Activity, Tools and Handling) and 3DSSPP (Three Dimensional static Strength Prediction Program) (both under section 2.5.1) in the week after the first focus group meeting with the participant installers (baseline phase) and at the intervention phase when the installers started working with the intervention items almost a month after the 3rd focus group meeting.

2.5.1.1. PATH (posture, activities, tools, and handling). A hierarchical taxonomy (Buchholz et al., 1996; Moir et al., 2003) was used to describe the process and to systematically categorize drywall work into s Buchholz mall units. These small units are the activities related to several drywall installation tasks. For example, the installation task is comprised of activities such as stepping on ladder, raising the panel, using screw gun to affix the panel and etc). We chose PATH (Buchholz et al., 1996) for quantification of biomechanical exposures. Procedures for PATH data collection into a PDA template can be found in Dasgupta et al., 2014.

For the baseline and intervention, PATH data was planned to be collected for the same workers and same tasks. Since, the template used for the drywall task is the same one as presented in Dasgupta et al., 2014, it is not described in this paper.

The following variables were compared between the baseline and intervention phases:

- Proportion of observed time with overhead or neutral arm postures (variable: 1 arm or 2 arms>60°)
- Proportion of observed time with non-neutral trunk posture *
- Proportion of observed time with heavy or medium load handled

The variables for non-neutral trunk postures were mild flexion or severe flexion, twist/bent, bent/twist &flex and extended trunk (Buchholz et al., 1996; Dasgupta et al., 2014).

2.5.1.2. Three Dimensional Static Strength Prediction Program (3DSSPP). The University of Michigan's Three Dimensional Static Strength Prediction Program (3DSSPP) software is capable of predicting joint moments and low-back muscle forces by using the body postural angles and loads lifted by the hands. The researcher recorded video and still photos of the installers while installing the drywall panels onto the ceiling at both the baseline and intervention phases.

Anthropometric measurements (height in cm and weight in pounds) of the same installers were also taken. A height measuring tape was used to mark the height of the installers while they stood against a wall. A weight-measuring instrument recorded their weight in pounds when they stepped on it. Individual installers' anthropometric data were entered into the software.

The video footage of the ceiling drywall installation task was broken into a sequence of static frames and the 3DSSPP software program used to analyze each of these individual static frames to calculate the shoulder moments and low back compressive force of each installer. The sequence of static postures was selected at 10-s intervals. Using the anthropometric values and the postures captured from the videos and still pictures, the compressive forces at the low back and moments produced at the shoulder joints were calculated. This entire process was followed for data from both the baseline and intervention phases.

The compressive forces at the low back and the moments produced at each shoulder joints were compared between the baseline and intervention phase using Students' t-tests.

2.5.2. Qualitative data collection: satisfaction on the intervention items

Qualitative data on satisfaction with the intervention were collected by survey one month after introducing the intervention. The installers did not use same equipment at both the phases except ladder for constricted spaces at the intervention phase. The total time of ceiling installation varied between the installers but each used the same intervention method to install the ceiling. After De Jong et al. (2003), the workers were asked to rate their satisfaction on specific categories (very satisfied, satisfied, moderately satisfied or not satisfied). In De Jong et al. (2003), the workers were asked to make choice on technical and organizational devices in terms of perceived reduction of physical load. Similarly, in this study the satisfaction survey had items on specific criteria of the intervention devices (ease of holding the 'deadman', raising the panels while being on lift etc.) and the workers were asked to make choice on their perceived satisfaction category for each criteria.

2.6. Evaluation of the intervention

Before - after comparison of exposures (for both PATH and 3DSSPP) was undertaken. Also, installers' perception on satisfaction and feedback on the intervention items were compared with the quantitative change in exposure.

3. Results

3.1. Study site and participants

This study location was a commercial residential construction site where a 12-story building was being built in Boston, MA.

The site had a total of five unionized drywall installers. All of them expressed interest to the foreman who in turn informed the researcher. These five participants were male, between 21 and 60 years of age, all right-handed, white Caucasian and English-speaking.

3.2. Equipment used at baseline phase

The installers were using 6′ ladders (90% of time) for ceiling installation. The workers seldom used buckets to inspect areas in the upperwall. However, those buckets were never used for ceiling installation. While using the ladders, the workers worked in pairs to install drywall on the ceiling and upper wall. The workers used a manually operated lift (10% time) (Fig. 1a) that helped them to raise the drywall panels (4′ × 8′ and 4′ × 12′) to the ceiling height.

3.3. Focus group meeting results

Table 1 summarizes the details of workers discussion in the focus group with the goal of finding an innovation for safer drywall installation.

At the first focus group meeting, installers showed concern about the ceiling drywall installation task and associated discomfort in upper body parts (shoulder, wrist) while holding panels to the ceiling. At the second meeting, installers could not agree on a concrete idea for lifting panels to the ceiling without exhausting their muscles. They made some suggestions like wearing stilts or having lighter weight panels but never concluded with a feasible solution.

At the third focus group meeting, one of the installers mentioned his past experience of using a 'deadman' at another job. The idea was liked by the other installers, who (at the request of the researcher) discussed the pros and cons of using this with an electrically operated lift (Fig. 1b) and compared it with the use of a manually operated lift (Fig. 1a). The installers also mentioned the heavy weight of the manually operated lift and associated discomfort of moving it from one floor to other floor. The workers perceived that they spent more time on ceiling installation while using the manual lift than the ladder. Also, some mentioned that the manually operated lift held a fixed 4′ × 8′ drywall panel and so not every piece could be installed with it.

Some of the installers tried to be in motion around while being on the ladder or the buckets at the baseline. These activities have been referred as 'laddering' and 'bucketing' in this paper.

3.4. Development of ideas into an 'innovative' intervention

In addition to the scheduled focus group meetings, all five installers spoke with the researcher informally, mostly at the beginning or end of their break time. The workers typically could spare 5–8 min for those meetings, usually arranged at the break time in the morning or at the end of the lunch break.

The installers informed the researcher whenever they received an update from the safety officer about how the idea of 'deadman' could be potentially implemented at that particular construction site. Through the observations of the researcher, although informal, the installers tended to be quite proactive in these informal meetings.

3.5. Equipment used at intervention

A 'deadman' (a narrow piece of scrap drywall panel) and an electrically operated lift for raising the drywall panels were the two intervention items that were developed through the focus group and informal meetings. They are referred to as the "intervention items" throughout this paper.

At the intervention, none of the baseline equipment except the ladder was used any longer. Ladder was used only for constricted spaces where the lift could not enter. The intervention items ('deadman' and electrically operated lift) were used primarily, with less use of ladder. The 'deadman' was used only in combination

Fig. 1. a: Use of manual lift. b: The electrical lift and the 'deadman'. c: Reaching upper wall while being on bucket.

with the electrically operated lift and was never used with the ladder (Table 3).

3.6. Time spent on ladder and lift at the intervention

At the intervention, the workers used the ladder and lift in an approximately 2:11 ratio. On average, for one hour of ceiling installation at the intervention, they spent 9 min on the ladder versus 51 min on the lift.

Hence, we found a total for 3 h of data that was collected at the intervention phase while using a ladder for ceiling installation.

The installers started working with the intervention items in pairs a month after the last formal focus group meeting. Fig. 1a, 1 b, and 1 c.

3.7. The baseline phase and the intervention phase: description of how a panel was installed to the ceiling

The following processes were used to install the ceiling at baseline:

3.7.1. Pair of installers using a ladder

A pair of installers used two adjacent ladders and raised the panels together while climbing their individual ladders. Upon reaching the ceiling, both used overhead arms to position the panel. One of them then continued to use his overhead arms to hold the panel in place while the other one used a screw gun to affix it permanently. Once one side of the panel was affixed, the installers interchanged their roles to affix the other side of the panel.

Table 1
Results of focus group meetings.

No.	Focus of discussion (n = number of participants)	Workers concern/ideas (n = number of workers with that opinion)
1	Which activity of the drywall installation task can be modified to reduce exposure? (n = 5)	The workers mostly discussed the activity where they supported the drywall with both hands overhead and especially while on a ladder. Specific answers included the following: • Learned to install drywall on a ladder but the shoulder hurts a lot while holding it (n = 4). • Having a bigger lift might help to reach the ceiling (n = 1). • Having a better screw gun to attach the drywall. Screwing is the most difficult activity since a lot of pressure is exerted on the wrist (n = 3)
2	Ways of lifting drywall to the ceiling without exhausting the muscles Other ideas instead of 'bucketing' and 'laddering' (n = 5)	• Having lightweight drywall panels will help (n = 2) • Wearing stilts to reach the upperwall might make it easy as there is no need to be on the ladder but a huge amount of time will be lost while attaching and detaching the stilts. • Also, the balance on stilts might be another problem while installation. (n = 3)
3	Any innovative ideas to install drywall to the ceiling that can be implemented at this site (n = 5)	• Scissor lifts are good as the drywall panels can be placed on the lift. Even if it reaches taller heights, installing the drywall at the ceiling will be same as installation while being on ladder. (n = 4) • The electrical lift might be good to reach the ceiling as the lift can hold upto 8 ft-12′ drywall panels. It can be used with a 'deadman'. The foreman might give the permission to use the electrical lift if there is space to move on it. (n = 5)

Table 1 shows workers concerns and solution ideas in the three consecutive meetings.

Table 2
Sequence of activities in the informal meetings (n = 5).

Which item was discussed	Where the installers showed concern	What action was taken to satisfy those concerns	Time period of the meetings
Electrical lift	Feasibility of using a lift	Not applicable	Between 2nd and 3rd focus group meeting (in the break time of the installers)
'Deadman'	Feasibility of its use at the site	The workers had shown two examples of 'deadman', one with a T shape and one as a long narrow drywall piece	A day after the 3rd focus group meeting
Electrical lift	The electrical lifts had wheels and could be moved	Workers decided to ask the foreman whether one of the lifts could be given for ceiling installation purpose. Two electrical lifts were present at the site, one was used for electrical work purposes.	Approx. two weeks after the 3rd focus group meeting
'Deadman'	Permission to use the 'deadman'	On asking the foreman and management for permission to use the 'deadman', the workers received it easily. Also, the safety officials gladly granted the use of an electrical lift with the use of the 'deadman'. The foreman thought that the device could make the workers faster compared to using a ladder.	Approx. 3.5 weeks after the 3rd focus group meeting (break time)

The ideas which were discussed during the informal meetings are detailed in Table 2, along with the chronological order in which the ideas were implemented.

Table 3
Difference in activities between the baseline and intervention.

Baseline phase (while using ladder)	Intervention phase (while using lift)
A pair of installers took the panel and walked towards the ladder.	A pair of installers loaded the panel on the lift and one of them boarded the lift.
They used both arms to manually raise the panels to the ceiling while they climbed on the ladder.	The panels were supported on the lift. When the panel was closer to the ceiling, the installer on the lift stopped the lift and raised the panels to the ceiling manually The installer on the floor raised the 'deadman' to the level of the ceiling to support it while the panel got positioned and affixed by the installer on the lift.
The installer on the ladder used one arm to support the ceiling drywall and used the screw gun with the other arm	The installer on the lift used one arm to use the screw gun while the ceiling panel was supported by the 'deadman'.
While using the manually operated lift:	The manual lift was not used at the intervention phase.
One installer placed a panel (8′/4′) on the panel holder of the lift. The pulley of the lift was manually moved in clockwise manner by which the panel was raised upto the level of the ceiling. The installer used a ladder to reach the ceiling height and used a screw gun to permanently affix the panel to the ceiling.	

*Data in column one shows while the workers are on the ladder at the baseline. Data in column two shows the steps carried out to install the drywall panels to the ceiling.

3.7.2. Single installer using a manually operated lift

The installers worked separately while using a manually operated lift to raise the panels to the ceiling. A single panel was placed on the lift and the installer rotated a wheel clockwise to raise the panel to the ceiling. Once it reached the ceiling, the installer climbed on a ladder, went up to ceiling height and used the screw gun to affix the panel permanently there.

3.7.3. Pair of installers using a electrically operated lift and 'deadman'

At the intervention phase, a pair of installers loaded the panel on the electrically operated lift and one of them boarded the lift. The panel remained supported on the lift while it moved toward the ceiling. When it was a short distance from the ceiling, the installer on the lift stopped the lift and started manually raising the panel to the ceiling. At this point, the 'deadman' was used to support the ceiling drywall by one worker on the ground (Fig. 1b). From this point onwards, the panel was continuously supported until its

permanent attachment to the ceiling. The 'deadman' was moved along the panel to give the other installer enough space to use the screw gun for permanent attachment purposes.

3.7.3.1. Difference in ceiling installation process between the baseline and intervention phases. At baseline, the installers worked individually while using the manually operated lift. The manually operated lift raised the panels to the ceiling. Then, a ladder was used to reach the ceiling where the same installer affixed the panels with a screw gun. The manually operated lift was never used at the intervention phase while the installers worked as pairs and used the ladders.

PATH observations indicated particularly notable differences between the sequence of activities to install drywall panels to the ceiling at the baseline and the intervention phase (Table 3).

At the intervention phase, the ladder was used for constricted spaces such as to fit drywall pieces around pipes, to cover the areas around the lights or to install in spaces around high voltage areas. The installers were on ladders to reach every part of such tight spaces. The manually operated lift was not used at the intervention phase.

3.8. Collected data

Data were collected on the five installers at the baseline and intervention for ceiling installation task.

A total of 46 h (2760 observations) of PATH data were collected for the baseline (23 h) and intervention (23 h) phases. Data were collected approximately from 7 am to 2 pm (including two breaks of total 1 h) for a week each for the baseline and intervention phase, for the months between late September and early December. The workers were installing both the sidewall and ceiling. PATH data were gathered at the time of ceiling installation task only.

The same five installers worked at the baseline and at the intervention period. The data was collected on the same five installers.

3.8.1. Average cycle time at the baseline and intervention

The average cycle time for each panel (4′ × 8′) installed while the workers were working on a ladder was 4 min and 30 s in average. It was 5 min and 30 s while the installers used the manually operated lift. The cycle time for each single panel (4′ × 8′) was 5 min at the intervention phase while using the electrically operated lift and 'deadman'.

3.8.2. Productivity at both phases

No data on number of panels installed were collected by the PATH method. However, anecdotally, there was no marked difference in the productivity at the two phases. The electrically operated lift was hired at the site for electrical work and the company paid $87/day for the lift.

3.9. Results of PATH analysis

At the intervention phase, the installers used the ladder to install the ceiling for the tight spaces. Although it was for a relatively less amount of time, the data are separated for the tight spaces ceiling installation and is shown separately in the figures.

3.9.1. Arm postures

Arm postures at or above shoulder level were observed frequently (37.4% ± 2.0% for one arm at or above 60° and 40.0% ± 2.2% for both arms above 60°) at baseline (Fig. 2). The highest proportion of work time with both arms >60° was observed while working on the ladder in tight spaces at the intervention phase (55.6% ± 2.2). Postures with one (27.8% ± 2.0) or both arms (27.0% ± 2.0) elevated above 60° were less frequently observed at the intervention phase while working with the intervention items. Neutral arm postures (arms down) were observed the most (45.4% ± 2.2) while working with the intervention items.

3.9.2. Trunk postures

The intervention phase (with lift and 'deadman') showed lower proportions of work time with non-neutral trunk posture (1.5% ± 0.6 of extension and 5.0% ± 1.0 of mild flexion, almost 0.0% for severe flexion) than the baseline phase (8.0% ± 1.2 extension, 10.0% ± 1.3 for bent/twist, 4.0% ± 1.0 bent/twist and flex) (Fig. 3).

3.9.3. Weight handling

The baseline phase shows higher amount of heavy load (≥50 lb) (3.1% ± 0.8), medium load (15 lb–49 lb) (4.5% ± 0.9) and light (5lb –15 lb) (4.6% ± 0.9) load handling than the intervention phase. Heavy load handling was absent while using the intervention items. At the intervention phase, the highest proportion of work time with heavy load handling (2.3% ± 0.7) was observed at the intervention phase while working on the ladder (Fig. 4). The highest amount of medium load and light load handling were observed during the ladder usage at the intervention phase (6.4% ± 1.1 for medium load and 4.6% ± 1.0 for light load).

3.9.4. Awkward arm and trunk postures while using ladder at both phases

Both arms in an elevated posture were more frequently observed when standing on a ladder (54.0%) during the intervention phase than at baseline (28.0%) (Fig. 5). The proportion of work time with bent or twisted trunk posture in the intervention phase ladder usage was 17.7% compared to 8% at baseline (Fig. 6).

3.10. 3DSSPP analysis

Biomechanical loading was compared for 4 installers who worked as pairs in both the baseline and intervention phases to install ceiling panels. The mean low back compressive force and left shoulder moment were significantly lower at the intervention phase than at baseline for the ceiling installation task (Table 4). There was no significant change in mean right shoulder moment for the same comparison.

The baseline and intervention mean value presented in Table 4 are the average of time weighted average for 4 installers for the ceiling installation task. The intervention mean is the average of the installers while being on the lift and while holding the 'deadman'. Table 5 shows the comparison between installer on the lift and installer with the 'deadman' at the intervention phase. Time weighted average for the same 4 installers were used as the data.

3.10.1. Difference between forces of the installers at the intervention (3DSSPP)

Table 5 shows the difference between the installer on lift and the installer on floor (with 'deadman') for compressive force and shoulder moment.

3.11. Qualitative evaluation results

3.11.1. Satisfaction with the intervention items

The perceptions of different specific characteristics of the innovation such as supporting the ceiling, using the screw gun, moving the deadman and etc. were positive (Table 6). Overall, it shows that the installers were very satisfied with the use of the intervention items.

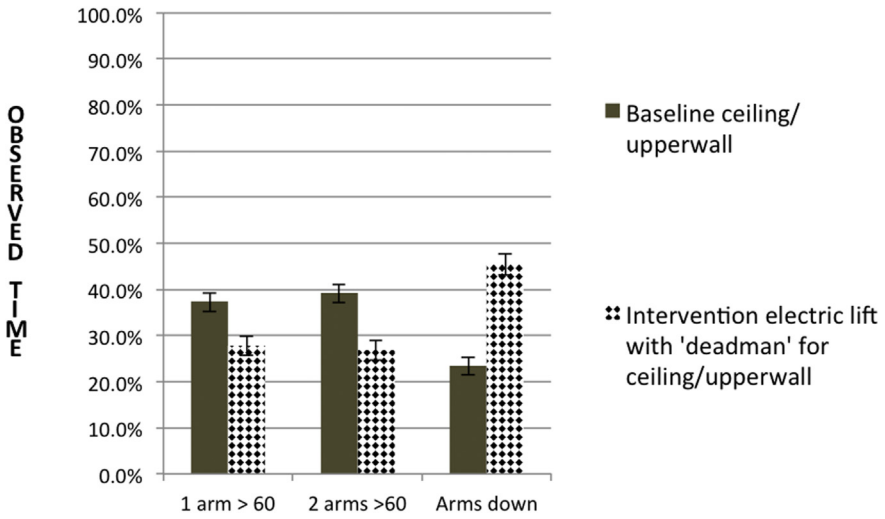

Fig. 2. Arm postures at baseline and intervention phases: percentage of observed time with 95% confidence interval.

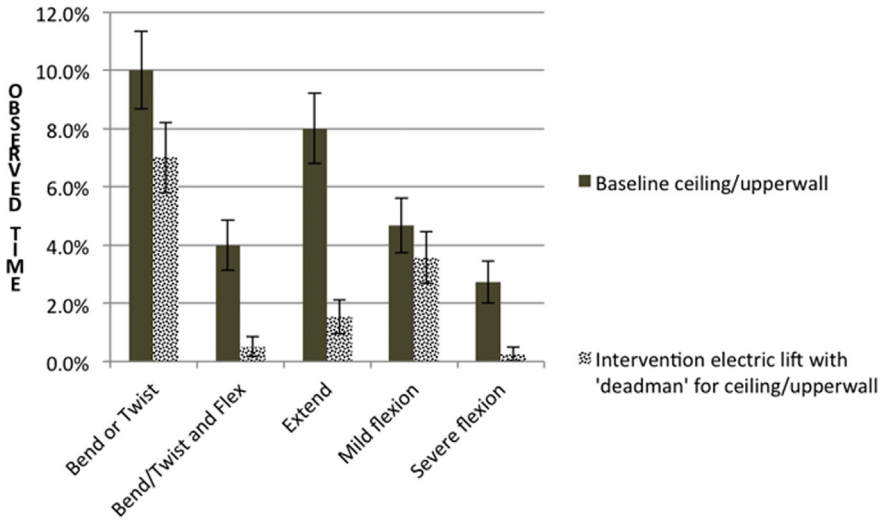

Fig. 3. Trunk postures at baseline and intervention phase.

3.11.2. Installers' perceived advantages and disadvantages of the intervention items

The installers who worked with the intervention were asked about the advantages and disadvantages of the 'deadman', in the questionnaire survey, through open-ended questions after the intervention phase. Overall, they thought that although the deadman was easy to store, use or manufacture, it could not be placed on its own and they had to hold it for long time. Their responses are summarized in Table 7.

Although, Tthere were some disadvantages related to the use of the 'deadman', the feasibility and ease of its use associated with the abundant supply of 'deadmen' outweighed those disadvantages.

3.12. Cost effectiveness of 'deadman'

The 'deadman' was structured from scarp drywall panel material which pointed towards a readily available material on the site, owing to the fact that no money was needed to buy it from market resource.

The electrically operated lift was rented and was part of an ongoing electrical work process at the site. It was not bought exclusively for the intervention. Technically, the lift, like the 'deadman', did not cost extra, though it would be a large expense if it were leased for the intervention purpose alone.

4. Discussion

This study engaged a small group of workers to develop and evaluate a solution for a known ergonomic hazard in drywall installation. The joint efforts of the workers and researcher led to development of a usable control measure, which was the combination of an electrically operated lift for raising the panels from the floor and a tool ('deadman') for supporting the panels against the ceiling while they were fastened. Although not widely used for drywall installation, the 'deadman' was not completely unknown to the working crew.

4.1. The impact of the intervention: outcome evaluation

Overall, the intervention led to a reduction in physical ergonomic exposures in drywall ceiling panel installation. The arms could be kept more often in a neutral posture because there was no

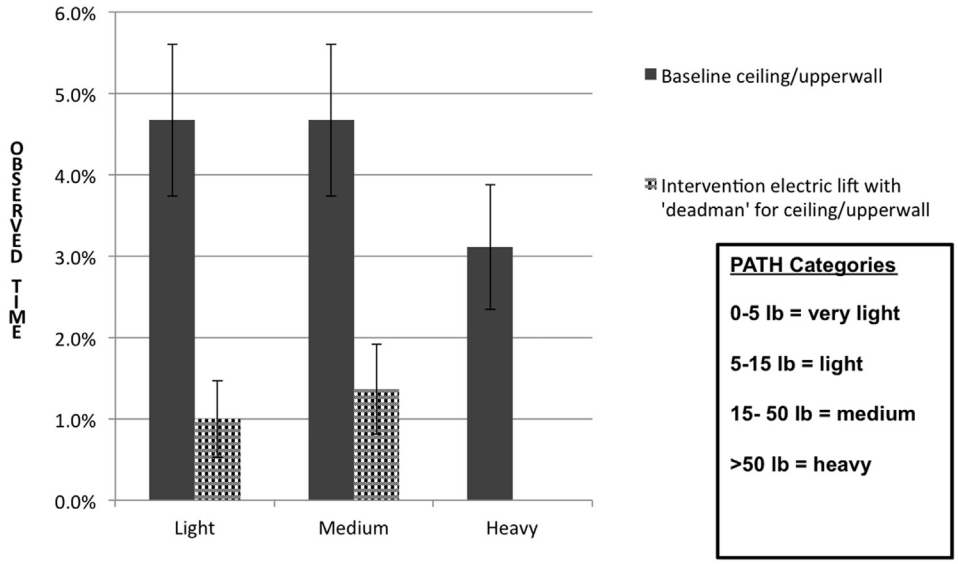

Fig. 4. Weight handling at baseline and intervention phase.

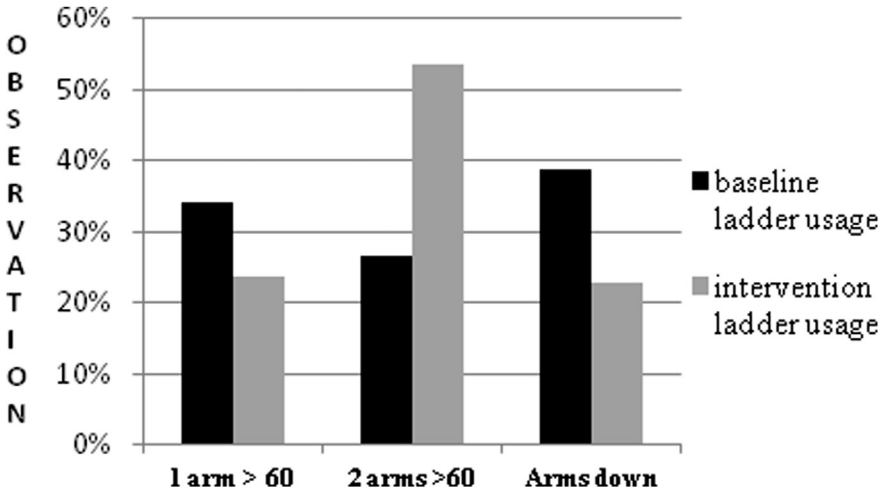

Fig. 5. Arm postures while using ladder at both phases.

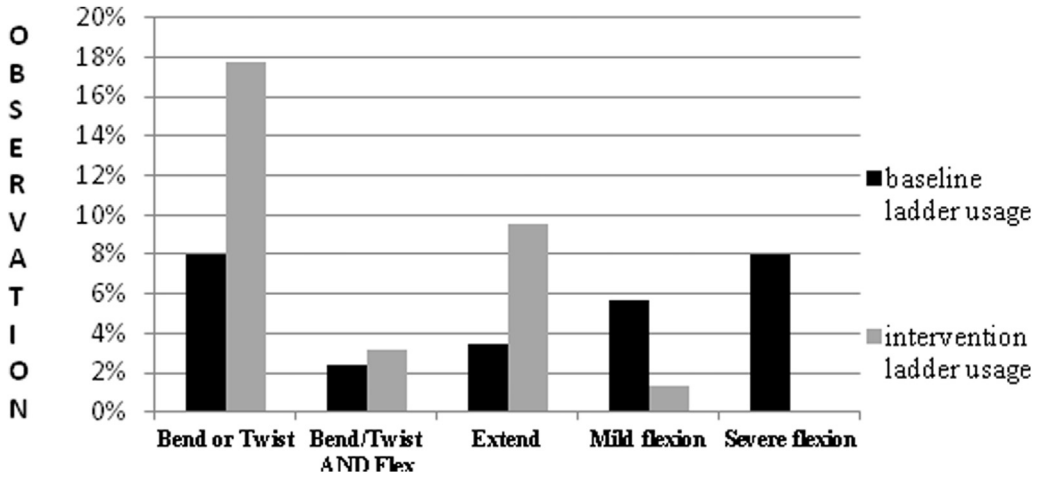

Fig. 6. Trunk postures while using ladder at both phases.

Table 4
Comparison between the biomechanical variables of the installers between baseline and intervention (n = 40, 4 inst*10 points).

Variable	Baseline mean (SD)	Intervention mean (SD)	p[a]
Low-back compressive force	2689.8 (971.5) N	1280.1 (680.2) N	0.001
Right shoulder moment	383.4 (256.5) N-m	311.8 (249.7) N-m	0.43
Left shoulder moment	556.4 (374.0) N-m	359.1 (233.5) N-m	0.04

Points are the seconds where the video was frozen to enter data to the 3DSSPP software.
[a] Student's t test.

Table 5
Comparison between the installer on lift and on 'deadman' (n = 32, 4 inst[a] 8 points).

Variable	Installer-on lift	Installer with deadman	P[a]
Low-back compressive force	1277.8 (154.6) N	947.4 (349.4) N	0.001
Right shoulder moment	326.1 (251.6) Nm	277.0 (224.7) Nm	0.50
Left shoulder moment	383.1 (221.7) Nm	201.9 (130.7) Nm	0.001

Points are the seconds where the video was frozen to enter data to the 3DSSPP software.
[a] Student's t test.

Table 6
Installers' perception of satisfaction while using the 'deadman'.

Intervention characteristics	Unsatisfied (n = 5)	Somewhat satisfied (n = 5)	Satisfied (n = 5)	Very satisfied (n = 5)
Supporting the ceiling by the 'deadman'	0/5	0/5	1/5	4/5
Screw gun usage on lift	0/5	1/5	2/5	2/5
Holding the 'deadman'	0/5	0/5	3/5	2/5
Raising the panels while being on the lift	0/5	0/5	1/5	4/5
Moving the 'deadman'	0	2/5	3/5	0

Table 7
Perceived advantages and disadvantages of the intervention items.

Advantages	Disadvantages
Easy to make from scrap, not costly	Trashed after the work is done
Avoids overhead arm postures	Must be held with hand
Can be kept anywhere at the site	Upward force has to be applied because the 'deadman' cannot stand on its own
Supply can be abundant	Has to be used with an electrical lift
Does not interrupt the production rate	Requires significant grip force

longer a need to lift the drywall panels manually and hold them in the air. The general satisfaction of the installers with the electrically operated lift coherently supports this quantitative evaluation. Satisfaction with the ceiling-supporting and panel-raising features of the innovation was particularly important because the workers had earlier identified these elements as physically stressful.

In addition, the intervention devices permitted the work to be done with fewer non-neutral trunk postures. Previously, standing on ladders required the workers to bend and twist the back in order to raise the panels to ceiling and hold them in place while fastening them. Thus, the reduction of awkward trunk postures was the effect of using the electrically operated lift instead of the ladder to reach the ceiling.

The intervention eliminated the need for heavy load handling (>50 lbs) through use of the electrically operated lift. Correspondingly, the biomechanical load moment at the left shoulder significantly decreased at the intervention phase, again because the need to hold the drywall panel in the air was greatly diminished. The reduction in right shoulder load moment was not significant, probably because all five of the installers used the right hand to operate the screw gun for attaching drywall.

The panels were loaded into the electrically operated lift by both the installers in a horizontal position. The installer on the lift used to hold one side of the panels till the panel was totally loaded into the lift. Although the weight of the panels caused moments, the heavier weight of the lift itself balanced those moments. Hence, it was very unlikely for the electrically operated lift to have a potential tip hazard.

4.2. Evaluating the intervention implementation process

4.2.1. Integrity of common ground between the researcher and the workers: a key to the implementation

This study illustrates how workers can utilize their expertise to find innovative solutions to the health and safety challenges at their workplace. Although effective discussions were carried out during the focus groups, the installers shared pivotal points with the researcher outside of those meetings. This showed that the installers continued to think about implementing the 'deadman' after the formal meetings were over, and that the researcher was able to gain their trust and confidence during the process. These informal conversations demonstrated their interest in seeing progress on the implementation (Table 4) and thus their real interest to use the 'deadman' for ceiling installation. Although the decision to permit them to use the electrically operated lift was made by the management, the workers' initiatives to make that happen is noteworthy.

Finding out a solution to reduce the exposures of ceiling installation task was the focus of this study. Introducing a solution within researcher's interest becomes harder than finding an

interest of the workers to build one. Hence the aim was constantly focused on receiving feasible and sustainable ideas from the installers. The aim was evidently satisfied as seen under Tables 1 and 2. The workers were clearly enthusiastic on materializing the idea of using a 'deadman' at the site. Their proactive discussion with the management on the intervention items and giving the update to the researcher establish that no influence was made by the researcher to make the interventions happen at the site.

4.3. Other precipitating factors behind the successful implementation

Another valuable contribution to the process was the role played by safety personnel, who had important concerns about the safety of the drywall job at this site. They were dissatisfied with the potential hazards of the 'laddering' and 'bucketing' (Fig. 1c) activities and perceived that the electrically operated lift and 'deadman' would be more stable and therefore safer. The safety officer therefore was an indirect 'importer' (Rogers, 2003) who spontaneously permitted to provide one of the two electrically operated lifts (that were present at the site for some electrical work) for ceiling installation and thus, offered pivotal support for the 'deadman' use.

4.4. Limitations and strengths of the study

One of the main limitations of this study is associated with convenience sampling of participants from only one construction site. Difficulty in gaining access to construction sites and obtaining consent to start intervention research in the construction field are very common and has been extensively experienced by the research team. Hence repeated personal contacts with safety personnel were required in order to recruit the construction site for this study. A sample of sites, randomized between intervention and control groups, would have been preferred but was impossible to obtain. It was also not possible to randomize individuals within the small sample size of five installers.

Due to extreme bureaucracy of the organization and harsh challenges faced while asking for an access into the site (Kidd et al., 2004), the research could not be repeated in other sites. The researchers actually developed a prototype based on the 'deadman' to structure a permanent solution for the hazards found in ceiling drywall installation. The cost of the electrical lift and necessity of wider space to move the lift might be other limitations the researchers would find to implement this intervention at construction sites.

We acknowledge that the intervention did not assess any biomechanical variables for any neck muscle flexion or extension, especially while holding the 'deadman' and looking upwards. Although it is a limitation, this posture was not maintained for a long stretch of time and is an unlikely source of exposure to neck muscle injury.

On the other hand, one important strength of this study was the substantial amount of direct observation time (total of 46 hours) for ceiling installation. The resultant PATH data set (2760 observation moments) was large enough to estimate reliably the effect of the intervention in reducing most exposures.

The use of ladders by a pair of installers for ceiling panel installation is a common practice and has been observed on other sites too. Hence, there is no reason to think that the results of this study would not be generalizable to other workers who perform ceiling installation.

There is possibility of a 'Hawthorne effect,' meaning the phenomenon of workers working differently than usual simply because of being observed by an outside researcher. While in some workplaces this cannot be ruled out totally, the researcher's presence on this site is unlikely to carry out the changes in exposure change between the baseline and intervention. The fact that the intervention items were used until the end of the entire construction job, approximately three months after the researcher left the site, gives salient proof to that. This strongly argues against the possibility that the success of the intervention was due to the Hawthorne effect.

PATH data showed that there were negligible differences between the installer on the lift and the installer holding the 'deadman' for awkward arm postures and amount of weight handled during ceiling installation at the intervention phase. The reduction of awkward arm postures was not due solely to the usage of an electrically operated lift. However, it is noteworthy to mention that the support offered by the 'deadman' piece prompted the worker on the lift to remove his overhead hand and use the screw gun to attach the ceiling. Also, no significant difference was observed for the compressive force and shoulder moments between the installer with the 'deadman' (on the floor) and the installer on the lift (Table 5). Hence, it is expected that a similar reduction in the installers' awkward postures would have been attained if the 'deadman' was used with a ladder.

Using 3DSSPP and PATH methods to quantify the exposure reduction amount for the ceiling installation activity further added to the strength of the study, because of the complementary types of data. Direct observation of the ceiling installation task at a real construction site, for 23 h before and 23 h during the intervention was introduced, gave a thorough picture of the work process. The modeling provided a detailed analysis of the biomechanical workload of the installers and the subsequent reduction of loading on the low back and shoulder joints in a real work setting.

However, there might have been low sensitivity to changes in load handled due to the wide intervals for "medium load" (15–50 lbs) and "heavy load" (>50lb) handled, as categorized in PATH. The moment when the weight of the ceiling panel is transferred to the support of the 'deadman', weight distribution of the panel remains the same at both ends (70lbs/2 = 35 lbs). For the installer on the floor there was an additional 14 lb weight from the 'deadman' itself, making a total of 49 lb. This according to the PATH category was considered as medium load handling, but only by a very narrow margin. Thus we may have underestimated the frequency of handling of "heavy loads".

This study is the first to evaluate the use of a 'deadman' as a technique to reduce physical ergonomic exposures during ceiling drywall installation, and the results were highly promising. Workers' trust development with the researcher proved to be vital for the study which concomitantly also showed the relevance of including the workers at the discussion level to develop a task-based solution. However, despite absence of a control group, the representative nature of the ceiling installation task indicates that the study results are likely generalizable.

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