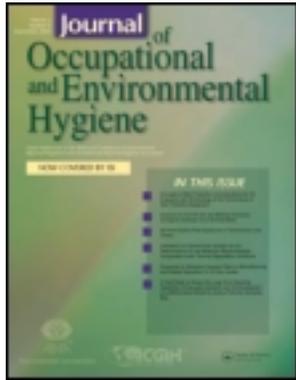


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## Journal of Occupational and Environmental Hygiene

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/uoeh20>

### Ergonomics

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Available online: 17 Aug 2010

To cite this article: Scott Schneider, Scott Fulmer, Samuel Agyem-Bediako & Bryan Buchholz (2004): Ergonomics, Journal of Occupational and Environmental Hygiene, 1:7, D80-D84

To link to this article: <http://dx.doi.org/10.1080/15459620490454462>

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# Ergonomics

## The Impact of an Intervention for Lifting Hazards During Installation of Overhead Electrical Conduit

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### INTRODUCTION

The construction industry has been shown to have high injury rates and the inherent ergonomic problems have been documented.<sup>(1–3)</sup> Musculoskeletal disorders, particularly back injuries, are a major concern in construction.<sup>(4)</sup> Low back pain and other injuries attributed to manual lifting activities<sup>(5)</sup> continue to be one of the leading occupational health and safety issues in all of preventive ergonomic medicine. Workers lifting and carrying equipment or materials can be injured when they twist repeatedly, work in awkward positions, or try to handle heavy loads without help.

Electricians play a significant role in construction processes. Electricians install, connect, test, and maintain electrical systems for a variety of purposes. Most electricians specialize in either construction or maintenance. In either case, electricians install conduit pipes, tubing for protecting electrical wires inside designated partitions, walls, or other concealed areas. The Massachusetts State Construction Industry Report for 2001 established that, among all trades, electricians and electrician apprentices had the state's fourth highest number of nonfatal injuries, with 375 days away from work.<sup>(6)</sup>

The objective of this study was to evaluate an intervention to reduce lifting hazards during installation of electrical conduit on a highway construction site. The electricians were responsible for identifying both the ergonomic hazard and the intervening control. The intervention that was implemented was a stand built on site (Figure 1) and used to store stock segments of electrical conduit closer to the point where they must ultimately be attached to an existing highway structure. The intent of the stand was to reduce the lifting distance, and specifically to reduce trunk flexion and forceful exertion, required to lift the segments to their destination.

Specifically, the purpose of this ergonomic exposure analysis was to:

- Quantify the effect of the intervention on ergonomic exposures to the electricians after its implementation; and
- Provide estimates of the frequencies electricians spend in various trunk, leg, and arm postures, as well as time spent doing manual material handling (MMH) activities during the “Install Conduit” operation.

### METHODS

#### Subjects

In this study, a crew of 14 electricians was observed working on a major highway construction site near Boston, Massachusetts. The construction project used union labor exclusively, and the observed crew was from the International Brotherhood of Electrical Workers, Local 103. Construction work on this project was maintained 24 hrs/day, and research observations were made on each of the three 8-hr shifts.

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The operation studied was “Install Conduit,” which is part of the “Traffic Control Devices” stage of highway construction.<sup>(3)</sup> This site required installation of 92,000 linear feet of conduit. The operation could be characterized by a handful of tasks and activities necessary to prepare materials to be assembled and installed. The conduit to be installed came in 10-ft long segments, and weighed approximately 80 lbs/segment. The operation required that the segments be lifted from the floor of the work area to the scissor lift by two workers, or, if available, a hand forklift. The scissor lift elevated the workers and the segments to the desired height. The workers then lifted the segments manually from the floor of the scissor lift to designated locations for installation. The segments were then attached to existing structures using braces and clips. The electricians moved the personnel lifts linearly as they proceeded, and inspected and adjusted the alignment of their work as necessary.

The intervention studied changed the origin of the lift from the floor of the scissor lift to a stand made out of wood. The stand was similar to a pair of sawhorses and was 28 in tall. Therefore, after the intervention, the conduit to be installed would be stacked 28 in off the floor of the lift, instead of directly on the floor, which reduced the vertical lifting distance by 28 in.

### Data Collection and Analysis

An Ergonomic Job Analysis (EJA)<sup>(7)</sup> was performed first to give a qualitative estimate of the risk factors present in the tasks for this operation. An EJA was also completed post-intervention to evaluate qualitatively the change in ergonomic risk factors.

The primary evaluation of the intervention was performed using the Three Dimensional Static Strength Prediction Program (3DSSPP) biomechanical modeling software.<sup>(8)</sup> The 3DSSPP gave estimates of L4/L5 intervertebral disc compression and ligament strain (the stretch in the ligament relative to its normal length), and other measures as well. Development of this model is described by Chaffin et al.<sup>(9)</sup> and Bean et al.<sup>(10)</sup> Compression forces on the intervertebral discs have been shown to be good predictors of low back pain symptoms.<sup>(11)</sup> A tape measure and a Wagner force gauge were used to measure the dimensions and weights of tools, mate-

rials, and equipment. Photographs were used to estimate the angles of the body segments necessary for the analysis. For the purpose of this analysis, the subject was assumed to be a 5 ft, 10 in male, and the weight of the conduit was assumed to be 40 lb, based on the observation that the 80-lb load was shared by two workers, one at each end of the segment.

In addition, an observational analysis was accomplished postintervention by using the PATH (Posture, Activities, Tools, and Handling) methodology.<sup>(12)</sup> PATH was employed to determine whether other risk factors still existed after implementation of the intervention. Data were collected on handheld computers at 60-sec intervals, using InspectWrite software (PenFact, Inc., Boston, Mass.). The data were then transferred to a PC and analyzed using EpiInfo (CDC, Atlanta, Ga.), according to the method described by Buchholz et al.<sup>(12)</sup>

## RESULTS

Table I shows the ergonomic hazards identified with the EJA that was performed on the install conduit operation. The intervention was implemented to reduce hazards in the activity of lifting conduit within the task of assemble/adjust conduit.

### Biomechanical Model

Compressive forces on the low back and ligament strain were estimated for five postures (Table II). The five postures were:

- Posture 1: Stooped posture while lifting from ground level
- Posture 2: Squat posture while lifting from ground level
- Posture 3: Lifting with one knee on the ground from ground level
- Posture 4: Lifting from the stand with moderate trunk flexion (Figure 1)
- Posture 5: Lifting from a higher stand eliminating the need for any trunk flexion

Postures 1–3 were observed preintervention and Posture 4 was observed postintervention. Posture 5 was hypothesized to correspond to an ideal lifting origin somewhat higher than the actual intervention.

**TABLE I. Ergonomic Hazards Identified**

Task	Activity	Hazard	Target Segment/Joint
Loading conduit pipes onto lifts	MMH (push/pull/drag)	Forceful exertion	Shoulder/arm/back
		Forceful exertion	Shoulder/arm/back
Assemble/adjustment of conduit pipes	Lift conduit	Awkward posture	Wrist/hand/arm
		Awkward posture	Arm
		Forceful exertion	Shoulder/arm
		Forceful exertion	Shoulder/arm
		Awkward posture	Arm
Inspection of work done	Tighten by wrench	Forceful exertion	Shoulder/arm
		Forceful exertion	Shoulder/arm
		Awkward posture	Arm
		Awkward posture	Arm
Inspection of work done	Whack	Forceful exertion	Shoulder/arm
		Awkward posture	Two arms up
		Awkward posture	Arm
Inspection of work done	Measure	Awkward posture	Two arms up
		Awkward posture	Two arms up
		Awkward posture	Two arms up
Inspection of work done	Brush/lubricate	Awkward posture	Two arms up
		Awkward posture	Two arms up
		Awkward posture	Two arms up

**TABLE II. Compression Force at L4/L5 and Ligament Strain as Estimated by the 3DSSPP**

Biomechanical Measure	Preintervention			Postintervention	
	Posture 1	Posture 2	Posture 3	Posture 4	Posture 5
L4/L5 compression force (lbs)	839	859	734	561	362
Ligament strain ( $\Delta L/L_0$ )	0.20	0.19	0.15	0.12	0.03

The intervention was estimated to reduce L4/L5 disc compression by 35% from as much as 859 lbs to 561 lbs and ligament strain by 40% from as much as 0.20 to 0.12. Lifting Posture 5 would yield much less L4/L5 disc compression force (reduced up to 58%) and ligament strain (reduced up to 85%) for an individual of average height, and demonstrated the advantage of a stand located at waist height. The advantage

reflected the height of the lift origin and its effect on the workers' need to bend during lifting.

#### **PATH Analysis**

Just over 1700 discrete PATH observations were made of the install conduit operation after implementation of the intervention. The trunk was neutral about 80% of the time (Table III). At



**FIGURE 1.** The intervention that was implemented was a stand built to reduce lifting distance, and specifically to reduce trunk flexion and forceful exertion. Moderate flexion was still required for an average height male.

**TABLE III. Percent of Time in Various Trunk Postures**

Trunk Posture	Frequency	Percent
Neutral	1338	78.6
Moderate forward flexion	157	9.2
Severe forward flexion	61	3.6
Lateral bend or twist	55	3.2
Lateral bend/twist and flexion	10	0.6
Extension	6	0.4
Not observed/applicable	75	4.4
Total	1702	100

least one arm was elevated almost 40% of the time (Table IV). The primary activities in this operation included MMH (14% of the time), assembling the materials by hand (13%), and then tightening them together with a wrench (14%). PATH data showed that handling the 10 ft. conduit still accounted for 18% of the work post-intervention (Table V).

## DISCUSSION

The electricians in this study had not been complaining of back pain, nor did they have formal ergonomic training. However, past experience and knowledge gave them the ability to recognize an ergonomic hazard that might lead to back pain, and they took steps to intervene. Most noteworthy in this study is that the electricians initiated their own actions and were supported by management to see that their ideas were implemented. In a cooperative process prescribed by the electrician foreman, carpenters built the stands to the specifications given to them by the electricians. The foreman indicated that this type of procedure was not unusual. Based on our observations on other sites, cross-trade communication *is* unusual even though communication with carpenters, the fabricators of jury-rig-type solutions on site, can be an exception. There was a general consensus that the intervention would help productivity, and some anecdotal evidence supported this assumption, but no formal measures were made to assess this.

The stand for storing the conduit on the personnel lift reduced the lifting distance to the existing overhead structure, the ultimate destination of the material. Once the intervention was implemented, the workers did not need to bend down to lift

**TABLE IV. Percent of Time in Various Shoulder Postures**

Arm/Shoulder Posture	Frequency	Percent
Neutral (both arms down)	973	57.2
One arm elevated	235	13.8
Both arms elevated	416	24.4
Not observed/applicable	78	4.6
Total	1702	100

**TABLE V. Percent of Time Observed Handling Various Materials**

Materials	Frequency	Percent
3 in. diam. conduit, 10 ft.	302	17.7
3 in. diam. conduit, 32 in.	24	1.4
1 in. diam. conduit, 10 ft.	24	1.4
Clip	210	12.3
Other (rack, brace, hanger, joint, nipples, etc.)	123	7.2
Not observed/applicable	1019	60.0
Total	1702	100

the conduit from the floor of the scissor lift. The height of the stand design was based on the practical advantage of having an even height between the stand and the middle rail of the lift. The height of the stand would affect individuals according to their height and their personal preferences. It could be possible to reduce ligament strain even further to fit different dimensions of workers, particularly if an intervening storage rack on the personnel lift were adjustable to fit the different sizes of the crew. The height of the stand, 28 in., was somewhat lower than the "power zone" height range recommended in the Occupational Safety and Health Administration (OSHA) Electrical Contractors eTool,<sup>(13)</sup> which is midthigh to mid-chest or between 28.4 in. and 50.2 in. for 50% of U.S. males or the optimal lift origin of 30 in. recommended by the National Institute for Occupational Safety and Health (NIOSH) in their lifting equation.<sup>(5)</sup> The electricians did not access objective ergonomic information in their design of the intervention. In fact, neither the electricians nor the contract managers were aware of the recently available eTool on the Internet.

The evaluation in this study was based primarily on estimated measures of ligament strain and disc compression, which has been shown to correlate with low back injuries.<sup>(11)</sup> The PATH observations were made only after the intervention was in place. Although trunk flexion still occurred, the workers were in a neutral trunk posture close to 80% of the time. The postintervention EJA showed that severe forward flexion was reduced, though moderate forward flexion may not have been. Although the data on exposure are generalizable to a certain degree, the ultimate measure of whether the intervention was successful would be a reduction of injuries to the lower back. Epidemiological studies have established that lifting from near the floor is associated with low back injuries.<sup>(14,15)</sup> Biomechanical studies support the concept that there is an increase in lumbar stress for lifting loads near the floor.<sup>(10,16)</sup> Significantly, lifting from near the floor has been identified by physiological studies to require a greater energy than lifting from raised heights.<sup>(17,18)</sup>

The PATH data also showed at least one arm elevated almost 40% of the time after the intervention was implemented. This is inherent to work near ceiling level and is difficult to intervene to reduce the amount of overhead work.<sup>(19)</sup>

Not all of the crew used the intervention. Interestingly, the stands were used only by the day shift, which had initiated and implemented the idea. Information about their use had been shared among the shifts, and individuals from each were free to use to their own satisfaction. The night shift individuals complained that the stands got in their way. As there were no observed increases in postural risk, the intervention clearly did more good than harm, which may be the most important determinant of effectiveness.<sup>(20)</sup>

Finally, the decisions made by the crew were affected by prior decisions at higher levels that precluded other ergonomic hazards from being reduced. For example, had the lateral space between the conduits been wider, more room would have been available. The additional room would have allowed the electricians to maintain a neutral trunk and shoulder posture because the neighboring conduit would not have been in the way. This would have required that the hanging racks supporting the conduit be manufactured differently, and that traffic below the installation would have to be managed differently. Other means and materials issues may have been involved, as well.

## ACKNOWLEDGMENT

The Construction Occupational Health Program (COHP) is part of a national effort to conduct research to increase the understanding of the health risk to workers in the construction industry and to reduce the exposure to those risks. The COHP works with both unions and contractors to conduct exposure assessments and to provide participatory approaches to interventions in the areas of ergonomics, industrial hygiene, and work environment policy. This report was produced with the support of a grant (grant #CCU731202) from NIOSH through the Center to Protect Workers' Rights (CPWR), which is the health and safety arm of the Building Trades Department of AFL/CIO. The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of NIOSH or CPWR.

The authors wish especially to thank the participating members of IBEW Local 103, and J.F. White Contracting Co., Inc., Electrical Division, and Lu Yuan and Sang Woo Tak for data collection and analysis.

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