Implementation of Safety and Health on Construction Sites, Singh, Hinze & Coble (eds)
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Technological interventions to reduce the incidents of back injury in building construction

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ABSTRACT: Occupational back injury represents an amazingly large segment of worker injuries and results in more lost work days than any other illness, second only to the common cold. Between 1985 and 1987, twelve states were surveyed and the results were astounding. Occupational back injury was found to be the most frequent work related disorder, accounting for 22% of all the reported cases and 32% of all workers' compensation dollars. The construction industry has consistently been considered a high risk industry for low back injuries. This paper presents the first results of a research project that has as its goals to identify hazardous tasks and to redesign existing workplaces, jobs, and equipment to fit the worker. The main portion of the paper is dedicated to discuss the steps that led to an ergonomic nailgun system that has been tested in the field.

1 INTRODUCTION

The most frequent injury to the common worker is lower back pain, generally the result of cumulative damage done to the spinal column area. Back pain is nothing new. It has afflicted man from the beginning of time; there is even evidence that primitive man suffered from some form of low back disease. Backaches, as common as they are, are very rarely lethal, but statistics show that they cause an extreme amount of misery. They tend to persist for years, sometimes even decades, flaring up from time to time, often for no apparent reason, and then subsiding again, just as mysteriously. These recurrent attacks of pain generally occur during a person's adult years, often interfering with the prime years of life.

Most of the advances and understanding of back injuries have occurred in the last 20 years. Enough books and articles have been written on the topic to fill an independent library. Along with the increase in interest and concern, the social and economical costs have risen as well. Back pain has, indeed, developed into man's most important non life-threatening disease. Despite all this, we still lack in knowledge about both cause and cure. In addition, we as humans lack in the necessary appreciation of its danger to a normal life.

1.1 *Occupational Back Injuries*

Occupational back injury is the leading cause of activity limitation among young adults, is the second most common reason for work absenteeism and is the third leading cause of work disability (Deyo and Diehl, 1988). Over the past 20 years, the number of persons permanently disabled as a result of low back pain has proportionately exceeded the population growth and the disability from other chronic health conditions . Between 1985 and 1987, twelve states were surveyed and the results were astounding. Occupational back injury was found to be the most frequent work related disorder, accounting for 22% of all the reported cases and 32% of all workers' compensation dollars (Federal Register, 1992). Over the past decade, workers' compensation benefits have increased 157% and employer costs have risen 143% (Nelson, 1993).

According to Malcolm Pope, the greatest potential for low back pain (LBP) prevention also exists in the workplace (Pope, M. et al. 1984). Incidence, severity, and potential disability are all related to the demands on the individual on the job.

1.2 *Back Injuries in Low-Rise Residential Construction*

Workers in the construction field are exposed to a number of recognized occupational risk factors for back pain including heavy work, materials handling, pushing, twisting, frequent lifting over 25 pounds, requirements for sudden unexpected maximum effort and a number of awkward postures (Bernold, 1993; Pope, 1984). Despite this, however, there has been very little research done relating specifically to occupational back problems among various construction trades. Interventions dealing with the prevention of construction related back problems is also a topic not often addressed.

During a four-year time frame in Ontario, Canada, data was collected by the Construction Safety Association of Ontario on lost time due to back injuries. It was found that the number of back injuries in the low-rise residential construction business greatly exceeded the injuries incurred by workers in other construction sectors. Low-rise residential building construction averaged about 22% of all back injuries in the construction industry. This distribution of back injuries by construction sectors can be seen in Figure 1. One explanation for this is the fact that the low-rise residential field employs more workers compared with the other sectors. Another explanation is that smaller contractors use less equipment and their material handling capabilities are limited.

Despite this fact, however, there is little literature specifically related to occupational back problems in construction. As a result, a growing concern for back injury in building construction has arisen, stemming from both the loss of productivity and the high cost of medical bills associated with the treatment of back injuries. The problem, thus, is how to decrease the incidents of back injury for the average worker in the construction industry while increasing productivity.

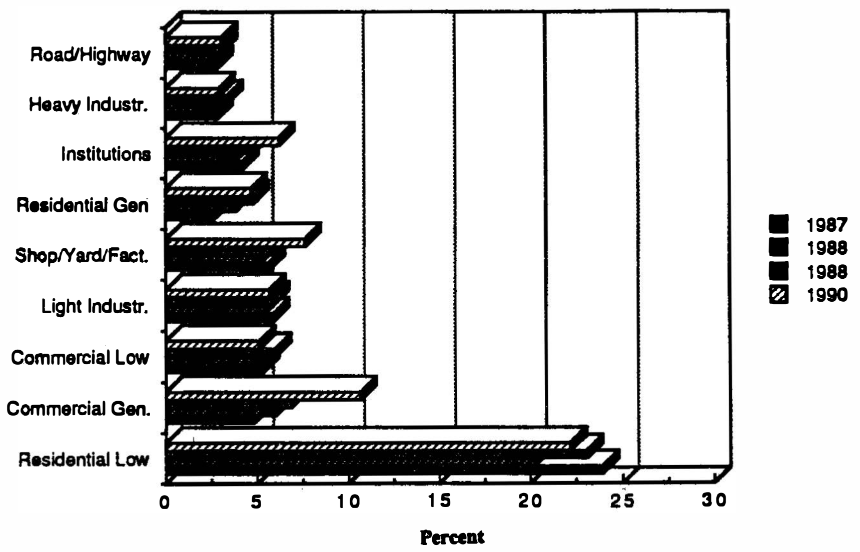

Figure 1. Distribution of Back Injuries by Construction Sector in Ontario, Canada (Bernold and Guler, 1993)

2 PROBLEM IDENTIFICATION AND ASSESSMENT

There exist several approaches to midigate the risks of back injuries on the job. One of the most promising are technological interventions that involve introducing ergonomics by redesigning existing workplaces, jobs, and equipment to fit the worker.

2.1 *Defining the Dangerous Tasks*

Three cooperating partners have joined forces to conquer this issue. Duke University Medical Center is responsible for conducting a symptom survey of a large sample of workers consisting exclusively of masons, carpenters, and roofers. The second partner, North Carolina State University's Industrial Engineering Department (Ergonomics Lab), is currently conducting extensive ergonomic analysis of various worker tasks (Mirka et. al., 1998). Biomechanical back stress associated with these specific tasks will also be assessed using the Lumbar Motion Monitor (LMM). The Construction Automation and Robotics Laboratory (CARL) at NC State University is the third participant in this research endeavor.

Construction workers are constantly exposed to a variety of differing job situations and must modify their behavior in accordance with the ever-changing circumstances. No two jobsites are ever exactly alike and even the same jobsite can change on a daily basis. Thus, it is essential to monitor jobsite conditions in order to identify "hazardous" tasks. First, a motion analysis of carpentry work on two residential construction sites was conducted; fifteen experienced workers from framing subcontractors were the chosen subjects involved in the study. Data was collected via continuous video analysis for the period of several workdays. After the videotaping was completed, each tape was analyzed with a video coding system. Using this approach, it was possible to continuously describe the biomechanical stress on each worker throughout the workday (Mirka, 1998).

Using this method of analyzing biomechanical stress, it becomes clearly apparent that certain activities are indeed back laboring and stress inducing. From the entire list of observed activities, six tasks were identified by ergonomic analysis as the greatest contributors to low back injury for carpentry workers. These tasks are:

1. Lifting raw materials from ground level
2. Working with power/air tools on ground level
3. Manually lifting trusses to the roof level
4. Carrying plywood flooring
5. Raising walls
6. Moving materials to the second floor

2.2 *Task Analysis*

The task of working with power/air tools on ground level was chosen for further analysis. In particular, the task of fastening plywood flooring to floor joists using a pneumatic nail gun, otherwise referred to as the subflooring task, became the focus of this research endeavor.

The subflooring task cycle basically involves three workers and tracks subflooring plywood from its initial location in the stockpile to its final placed position on the floor of the house being constructed. The first worker fetches the plywood sheet from the stockpile and transports it to his sawhorse cutting location. Here, Worker #1 measures the plywood and cuts it to its necessary size. After this task is complete, Worker #1 picks up the cut plywood and carries it to the construction area. More often than not, Worker #1 completes his task at ground elevation and the plywood is transferred to Worker #2, who is on the building foundation. Worker #2 bends over and picks up the sheet of subflooring plywood. He then carries the plywood to the location that it is needed and places it horizontally on top of the floor joists. Using a rubber mallet, Worker #2 guides the plywood into position by hitting its edges. His job with this section of subflooring is now complete and Worker #3's job begins. The plywood

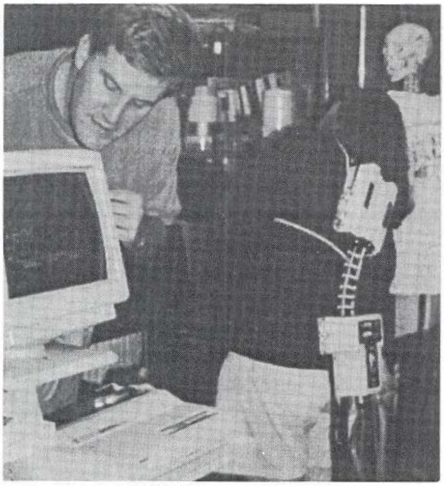

Figure 2. Laboratory Test with Lumbar Motion Monitor

must now be fastened to the floor joists. This task is generally done with the application of nails by a pneumatic nail gun. Worker #3 must bend over at the waist and apply numerous nails into the sheet of plywood, taking care to position his nail gun in such a manner as to attach the plywood to the underlying floor joists. The subflooring cycle is now complete.

2.3 *Measurements of Stresses on Back*

For the purpose assessing the stress that the nailing task exerted on the back of a human a Lumbar Motion Monitor (LMM) system was used. It is data collection device that allows objective and quantitative measurements of the lumbar range of motion, velocity, and acceleration while a human is performing specific tasks. The LMM is an exoskeleton of the spine that has been instrumented with sensors and fitted to the subject as shown in Figure 2. The outputs of the sensors are transmitted through an umbilical cable to the A/D board in a personal computer. The computer then calculates the instantaneous position, velocity, and acceleration of the lumbar spine during the engaged activity.

Three subjects were chosen to perform the task of nailing plywood sheets to floor joists in a controlled laboratory setting. All subjects were familiar with the use of the pneumatic nail gun and all were of approximately mean stature for the male population. In this fashion, each worker nailed 2 sheets of plywood to the floor joists; each sheet required 5 rows of 4 nails, totaling 20 nails per sheet of plywood. Table 1 present the results of the averages of all the conducted tests.

Table 1: Results of Lumbar Motion Monitor for Traditional Nailing

	LP	LV	LA	SP	SV	SA	TP	TV	TA
Trad. Nailing	-4.9	5.5	26.7	66.9	6.4	28.8	-9.7	2.4	14.0

(L = lateral; S = sagittal; T = transverse; P = position; V = velocity; A = acceleration)
(Position measured in degrees; Velocity measured in degrees per second; Acceleration measured in degrees per second^2)

As expected, the largest motions are measured in the sagittal position (SP), which is the forward bending of the trunk. With 66.9 degrees, it represents the quantitative measure of the large bending motion, while the -9.4 degrees of TP represents the much smaller rotation of the trunk during bending. This data demonstrates that nailing with one hand is not just a simple bending operation, Due to the fact that the worker must extend one hand further away from his body then the other, the upper body has to rotate above the hip. As a result, the total stress on the spine is the product adding bending- and torque-stresses together.

Since the small weight of the nailgun itself does not result in large stresses from nailing one nail, the cumulative or repetitive motion of nailing is significant. In fact, the video analysis of the site operations showed that the nailing of the subfloor will take a significant amount of time, followed by the assembly and nailing of wall frames, done on the finished floor. The extended duration of operating the nailgun in a bend-over posture was the main reason why this operation was identified as one of the most "hazardous" tasks.

After the nailgun operation on the ground level was identified and its impact on the spine studied, an technological intervention was thought.

3 DEVELOPMENT OF A TECHNOLOGICAL INTERVENTION

In order to reduce the risk of getting a back injury due to operating a nailgun, a variety of approaches can and have been taken. They include, exercise, setting material on work horses, etc. Due to a variety of reasons, the research team decided to develop a technological solution to the problem by redesigning the nailgun in such a way that it could be operated from a standing position. The resulting device was called the Ergonomic Nailing System (ENS).

The ENS is an attachment that serves as an extension device that is able to handle any commercial pneumatic nail gun. The ENS is attached to the nail gun with two Velcro straps on the handle and two adjustable braces. Key features which make the system unique are its:

- Ergonomically correct design
- Lightweight aluminum structure
- Height and angle adjustment capability
- Trigger operation at waist level
- Adaptability to any pneumatic nail gun
- Mobility with the use of multidirectional, height adjustable casters
- Safe operation by utilizing the safety mechanisms of the nail gun itself
- Quick and efficient method of attaching and detaching nail gun.

The Ergonomic Nailing System, as pictured in Figures 3 and 4, has a lightweight aluminum tubing handle that is both height and angle adjustable. The trigger is located on the right handle grip and is operated with two or more fingers. A cable connects the finger trigger and the actual trigger housing mechanism. This housing mechanism engages the trigger of the pneumatic nail gun. This special housing mechanism allows only one nail to be shot at a time and is only operational when the nail gun is in the correct position for nailing. The entire device is completely mobile in all directions, with the addition of two multidirectional, height adjustable casters.

In order to disengage the first safety, the worker must push the handle away from his body to depress the front safety at the point of impact. With the front end down, the worker can now squeeze the trigger and discharge a nail. He must, at this point, raise the front of the nail gun by pulling the handle back towards his waist. This can be done while gliding the nail gun to its next position. Because the casters are multidirectional, the worker is not limited to a specific sequence of nailing and can go back and forth with ease.

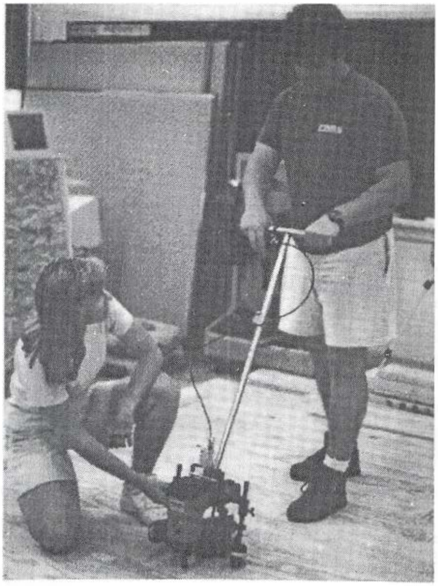

Figure 3. First Prototype During Laboratory Testing

4 COMPARATIVE EVALUATIONS

In order to assess quantitatively the effect of the ENS, the controlled laboratory tests using the LMM were repeated using the new prototype.

4.1 *Controlled Laboratory Tests*

Again, each participant wore the Lumbar Motion Monitor (LMM) on his back during the laboratory testing period, in order to quantify the amount of bending involved.

The results of the controlled laboratory testing, (Table 2) revealed that the Ergonomic Nailing System drastically reduced the average trunk sagittal position (SP), which is the forward bending of the trunk. Trunk bending was decreased from 66.9 degrees to 12.4 degrees. This reduction resulted from the elimination of forward bending usually involved in the task of nailing. In addition, the trunk transverse position (TP) or the rotation of the trunk, was reduced from –9.4 degrees to –4.4 degrees. Since the worker no longer has to rotate his body while nailing, the rotation of the trunk is greatly reduced. Both of these differences were statistically significant at the $p<0.0001$ level.

After analyzing the videotapes of the controlled laboratory testing and the accompanying LMM data, it was noted that the use of the Ergonomic Nailing System required the subjects to rotate their bodies to the side to view the exact point of impact of the nail gun.

Table 2: Lumbar Motion Monitor Results

	LP	LV	LA	SP	SV	SA	TP	TV	TA
Trad. Nailing	-4.9	5.5	26.7	66.9	6.4	28.8	-9.7	2.4	14.0
ENS	-6.9	6.3	27.1	12.4	6.3	29.7	-4.4	3.0	15.8

(L = lateral; S = sagittal; T = transverse; P = position; V = velocity; A = acceleration)
(Position measured in degrees; Velocity measured in degrees per second; Acceleration measured in degrees per second per second)

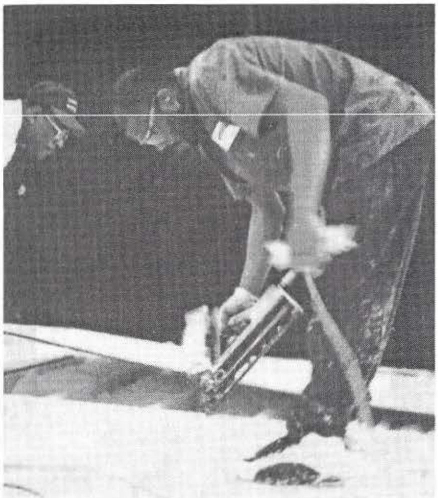

Figure 4. Pneumatic Nailing of Subfloor for Manufactured Houses

In order to solve this problem, a mirror mounted on the frame of the ENS was added to the design. This mirror allows workers to view the exact point of impact without rotating their bodies unnecessarily.

4.2 *Comparative Field Tests*

In order to prove that the ENS would actually work in the field, a comparative field experiment was designed. It was decided to focus first on the nailing process during the prefabrication of manufactured houses. Since this process is highly repetitive inside a covered space a true comparison was possible. Figure 4 shows the present nailing of the subfloor.

As depicted in Figure 4, the worker operates the large nailgun by bending over. Each time one nail is "shot", he experiences a recoil effect in his arm and upper body. While the same worker operates the nailgun during the day (e.g., dedicated nailgun operator), he has to interrupt frequently and sometimes for a long time. Some of the reasons include: 1) Refilling the nailgun with a strap of new nails, 2) lack of plywood sheets, 3) adjusting plywood, 4) pushing completed floor to next work station, and 5) breaks during the day. While the nailgun is in use, however, the operator is capable of nailing 2 nails a second. As can also be seen on the picture, the handle of the nailgun is drastically different then the nailguns commonly found in building construction. Before any field test could be conducted it was necessary to modify the ENS. The resulting second prototype, as shown in Figure 5, was eventually used for the test.

The experimental tests, with and without the use of the ENS, were videotaped for later analysis. A quantitative comparison of the two system did not show any reduction in the amount of nails the the operator was able to "shoot". The comparative tests allowed the researchers to make following important observations: 1) The new tool was immediately embraced by the nailgun operator because he wanted to get rid of his back pain, 2) no learning effects could be assessed, 3) the recoil effect on the body was eliminated and immediately recognized by the worker, 4) the selected trigger mechanism required too much movement of the right hand, and 5) wheel assembly created difficulties when the operator had to nail around protruding (pre-installed) conduits.

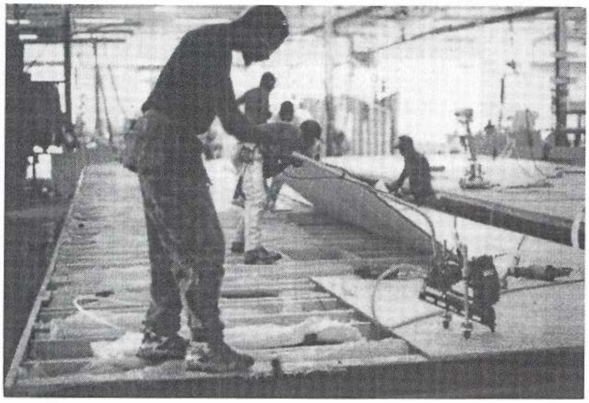

Figure 5. Second Prototype of the ENS During Field Testing

5 SUMMARY AND CONCLUSION

Occupational back injuries are on the rise and seem to be universal,. Due to its large impact on the life of people and the related cost, it *should* be prevented at all costs. This paper presented one approach, technological interventions, namely a simple and advanced engineering solution to the operation of nailguns in building construction. After an extensive period of site observation and analysis, the process of nailing sub-floors was identified as a high-risk operation. Based on the nature of the work, the Ergonomic Nailing System (ENS) was designed, prototyped, and tested in the field. The first comparative tests showed that the proposed simple system works well in the field of manufactured housing, is immediately embraced by workers that suffer from constant bending during nailing, and does not result in loss of productivity. Laboratory tests also showed the drastic change of this innovative system on the sagittal position of the human, who is not required to bend anymore.

6 ACKNOWLEDGEMENTS

This publication was supported by Grant Number 5R01/CCR413061-02 from the National Institute of Occupational Safety and Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official view of the National Institute for Occupational Safety and Health.

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PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE OF CIB WORKING COMMISSION W99 / HONOLULU / HAWAII / 24-27 MARCH 1999

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A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1999