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Ergonomics, Health, and Safety in Construction: Opportunities for Automation and Robotics

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ABSTRACT

Automation and robotics have often been mentioned as possible solutions to health and safety problems in construction. Several studies have prioritized automation and robotics opportunities based in part on health and safety considerations. These and other studies conclude that automation and robotics will be most cost effective in tasks that require speed, repetitive motions, large forces, and operation in hostile environments. These are precisely the tasks that place craft workers at the highest risk for overexertion injuries and disorders. Overexertion injuries are the single largest classification of injury in construction in the United States, accounting for about 24% of all injuries. Overexertion injuries generally occur as a result of performing a given task as planned. While overexertion injuries are not intentional, the underlying causes of the injuries are built into the prescribed tools and work methods. This paper describes a current research project that will identify specific construction tasks that place craft workers at high risk for overexertion injuries and disorders. High risk tasks can then be targeted so that automation, robotics, and ergonomic principles can be applied to modify the task or work environment to accommodate human capabilities and limitations.

INTRODUCTION

The construction industry in general has one of the worst occupational health and safety records of any U.S. industry. The construction industry employs about 5% of the work force, but accounts for 11% of occupational injuries and 18% of all occupational fatalities (*Accident* 1992). Overexertion injuries resulting from work activities (e.g. low back pain, cervicobrachial disorders, and upper extremity cumulative trauma injuries) are the single largest classification of injury in construction in the United States, accounting for about 24% of all injuries (*Construction Accidents* 1992). The Bureau of Labor Statistics and OSHA classify overexertion injuries as "nonimpact cases in which the injury resulted from excessive physical effort, as in lifting, pulling, pushing wielding, or throwing the source of injury. Includes conditions resulting from repetitive motion in the use of hand tools" (*Method* 1962).

In 1986, overexertion injuries were reported at a rate of about 3 per 10,000 full time workers in all industries. In 1991, the rate was 31 per 10,000 full time workers (*Monthly* 1991). Increased recognition by the medical community, insurance carriers, and by the workers themselves has contributed to this dramatic increase in reporting of these injuries. Because cumulative trauma disorders and other overexertion injuries tend to be "unreported or misdiagnosed, statistics on the extent of the problem in construction are elusive. Nonetheless, 'All the crafts have it,' claims Jim E. Lapping, director of the AFL-CIO Building and Construction Trades Dept." (*Repeat* 1989).

As bad as the construction industry's safety record is, it is likely to get worse if current practices continue. Demographic projections show that the age of the U.S. civilian work force is increasing, from a median 34.3 years in 1980 to a predicted 40.6 years in 2005 (*Monthly* 1991). While older construction craft workers generally experience lower injury rates than younger workers (*Construction Accidents* 1992), probably due to their increased awareness of the hazards of the work (Oglesby et al 1989), the consequences of injuries (e.g. length of hospital stay, days of lost or restricted work, permanent disability) are more serious for older workers (Dillingham 1981). The Bureau of Labor Statistics (*Projections* 1988) projects that there will be about one million additional workers age 45 and above each year for the next 20 years. The trend is largely due to the aging of the baby-boom generation. By 2005, 15 percent of the workforce is projected to be 55 years or older.

Workers of either gender gradually lose strength as they age. The strength of an average 65 year old person is only 75-80 percent of the peak strength that occurs about age 20 (Astrand and Rodahl 1986). Older workers also have reduced postural flexibility making them more susceptible to back injuries (Helander 1981).

Demographic projections also show that the percentage of women in the workforce in increasing (Johnston and Packer 1987). Today, only about 3% of the construction workforce is female (Ichniowski 1993). Compared to males, females are shorter, lighter, have lower strength and lower anaerobic power, forcing females to work at a higher percentage (compared to males at similar production rates) of their maximum capacities and making them more vulnerable to overexertion injuries (Helander 1981, Astrand and Rodahl 1986).

The construction work force has traditionally been composed primarily of young males. With increasing numbers of women and older workers in construction, it is increasingly imperative to reduce the risk exposure to overexertion injuries. An important strategy in reducing risk is the application of automation and robotics in high risk tasks.

Overexertion injuries generally occur as a result of performing a given task as planned. While overexertion injuries are not intentional, the underlying causes of the injuries are built into the prescribed tools and work methods. If the causes can be identified, it should be possible to engineer them out of the work. This is in contrast to other types of injuries (e.g. struck by, fall from elevation, struck against, fall same level, etc.) which occur due to an error or unplanned event. These so-called traumatic accidents are not intentionally built into the task. Reducing traumatic injury rates requires a totally different type of workplace intervention compared to overexertion injuries.

Once afflicted with an overexertion injury, many construction craft workers can be excessively challenged by the physical demands of their jobs. If the worker has the requisite skills and if alternative less-demanding employment is available, the worker can seek a different job where demands are better matched to physical capacity and ability. If alternative work cannot be found, the injured worker faces the dilemma of continuing at a job that causes excess fatigue or discomfort, or perhaps dropping out of the workforce. In their analysis of labor force withdrawal patterns among U.S. men, Hayward et al (1989) found that white collar professionals and managers have relatively low rates of retirement and that their careers extend into relatively old ages. This is in contrast to the pattern for physically demanding jobs such as construction crafts and laborers who had intermediate to high early retirement rates.

Despite advances in technology, including automation and robotics, construction remains a physically strenuous occupation. In the *Jobs Rated Almanac* ranking of 250 jobs for physical demands, construction trades account for 15 of the worst 50 jobs (Krantz 1992). Except for earthmoving equipment and cranes, highly capital intensive automation and robotic equipment that has become widespread in many manufacturing industries has not gained acceptance in construction. The culture of the construction industry has evolved such that contractors rely heavily on hand labor with small, relatively inexpensive, multipurpose tools.

Compared to many blue collar industries, construction craft workers are highly skilled, highly trained individuals. A major problem facing the construction industry is the shortage of skilled labor (*Construction Technology* 1982). High accident and injury rates are often cited as reasons why young people entering the workforce shy away from construction.

By the time many young construction workers have completed four year union apprenticeship training programs, they are unable to work in the trade for which they are trained due to overexertion and other injuries. This results in waste of all the time and money invested in training the individual and exacerbates existing skill labor shortages.

Automation and robotics have often been mentioned as possible solutions to health and safety problems in construction. Indeed, several studies have prioritized automation and robotics opportunities based in part on health and safety considerations (e.g. *Construction Technology* 1982, Kangari and Halpin 1989, Tucker et al 1990, Everett 1991). These and other studies conclude that automation and robotics will be most cost effective in tasks that require speed, repetitive motions, large forces, and operation in hostile environments. These are precisely the tasks that place craft workers at the highest risk for overexertion injuries and disorders.

The objective of this paper is to describe a current research project that will identify specific construction tasks that place craft workers at high risk for overexertion injuries and disorders. High risk tasks can then be targeted so that automation, robotics, and ergonomic principles can be applied to modify the task or work environment to accommodate human capabilities and limitations. We hypothesize that it is possible to identify the underlying causes of overexertion injuries for many specific construction tasks and that it is technically and economically feasible on many construction tasks to reduce the level of physical demands placed on craft workers by introducing automation and robotics technology.

RESEARCH DESIGN AND METHODS

Construction injuries have been categorized in many ways, including by trade (e.g. carpenters, electricians, laborers, etc.) but no attempt has been made to identify a causal relationship between specific tasks within a trade and the associated overexertion injuries. For example, carpenters account for 17% of all injuries and illnesses (*Construction Accidents* 1992), but carpenters perform many fundamentally different tasks such as erecting concrete formwork, installing suspended ceilings, hanging drywall, etc. Ed Nyhus, Business Manager of the Carpenters Union Local 512 (southeast Michigan) reports that carpenters who install formwork for concrete experience high rates of tendinitis in their elbows from banging the forms and connectors with hammers, carpenters who install suspended ceiling systems experience neck and shoulder problems from constantly looking and reaching up, and carpenters who hang drywall often suffer nerve damage in their hands from the vibration of the screwguns used to fasten the drywall to the framing system. All of these injuries fall into the general classification of overexertion injuries to carpenters, but the underlying causes are quite different and they call for fundamentally different types of workplace intervention.

The first step in this project has been to solicit the participation of construction industry practitioners, particularly craft workers. Liker et al (1989) have shown that joint management-labor ergonomics programs are most effective. The craft workers have the best knowledge of what they do on a day-to-day basis and how they perform their daily routines.

Managers have the resources to implement interventions and changes and often have the final determination of how the work will be performed.

The nature of construction work requires craft workers to be able to perform many different tasks. However, on all but the smallest projects, craft workers tend to become specialized and spend a large fraction of their time performing essentially the same task over and over for weeks, months, or years.

In union construction, the assignment of specific tasks to members of specific trade unions is very well defined in local practice and in collective bargaining agreements. In fact, this characteristic of union construction is such an important issue that jurisdictional disputes arise when members of one union attempt to perform work claimed by another union. Whatever the merits of this system may be, for the purposes of this project, it is convenient to catalog different construction tasks according to the trade union that normally performs the task.

There are fifteen building trade unions affiliated with the AFL-CIO: iron workers, insulators, boilermakers, electricians, painters, bricklayers, elevator constructors, operating engineers, laborers, cement finishers, sheet metal workers, tile workers, plumbers, carpenters, and roofers. Several local chapters of these national or international unions have agreed to define, step by step, each of their tasks. An example of the level of detail to which each task will be scrutinized is shown below.

Each construction task will then be evaluated for the presence of generic risk factors for overexertion injuries. Armstrong (1993) has defined these seven ergonomic stresses or generic risk factors:

Repetitive exertions	Performing the same acts or motions over and over again
Static exertions	Maintenance of the same position of the body or some part of the body throughout each work cycle or for prolonged periods
Forceful exertions	An exertion performed to overcome weight, resistance, or inertia of the body or a work object
Localized mechanical stresses	Mechanical tissue stresses in the area of contact with external objects
Posture stresses	Positions of the body that require more effort than others or result in compression or stretching of tissues in or around the joints, e.g. nerves or tendons
Low temperature	Contact of the hand with air or work objects below 20°C or exposure of the worker to low ambient temperatures that result in reduced peripheral circulation
Vibration	Contact of the hands with vibrating objects

Each construction task will be broken into its constituent steps as described below. Each step will be rated on a scale of 1 to 3, corresponding to an ordinal scoring system (Keyserling and Wittig 1988) where:

1 = Insignificant: The job is free of potentially harmful ergonomic stresses in the risk factor of interest. No corrective actions are necessary.

2 = Moderate: The job has stresses in the risk factor of interest that could be problematic (i.e. cause fatigue and/or injury) for some workers. Additional analyses using more precise methods should be used to determine the necessity for intervention.

3 = High: The job has significant stresses in the risk factor of interest that are likely to cause fatigue and/or injury in some workers. Additional analyses and interventions should be taken at a high priority.

Some of the possible quantitative assessments of exposure to the seven generic risk factors include (Armstrong 1993):

<u>Repeated exertions</u>

Exertions or movements per unit time
Exertion time as fraction of task cycle
Time performing continuous task

<u>Static exertions</u>

Ordinal scale for rating repetitiveness

- Very low: Idle most of the time
- Low: frequent pauses to wait for equipment or rest, no difficulty keeping up
- Medium: steady motion but leisurely pace and no difficulty keeping up
- High: Hands or body in rapid motion
- Very high: Body parts are in constant motion, difficulty keeping up

<u>Forceful exertions</u>

Load: weight of tools and work objects; resistance of joining parts, moving controls, moving materials
Friction: between handle and work object surfaces; gloves
Mechanical assists: jigs and fixtures supporting work object; hoists
Balance: hand or body position versus center of gravity; tools; work materials
Torque: shape of tools, e.g. in line, pistol grip, right angle grip; reaction bars

<u>Localized mechanical stresses</u>

Stress = Force/Area
Irritation of skin and underlying tissues, tendons and tendon sheaths, nerves
Sensitive areas of body
Type of contact: edges and corners of work objects and tools
Contact duration: continuous or intermittent

<u>Posture stresses</u>

Positions of joints and body parts: elevated elbows; reaching behind torso; extreme flexion, outward or inward rotation of elbow; extreme flexion, extension, ulnar deviation or radial deviation of wrist; bending over; deep squat, etc.
Duration of stressful postures: continuous or intermittent

Low temperature

Contact of the hand or other body parts with air or work objects below 20°C
Exposure to low ambient temperatures that result in reduced peripheral circulation

Vibration

Whole body vibration (jackhammers, earthmoving equipment)
Hand tool vibration, does vibration effect how craft worker holds tool?
Duration of vibration exposure: continuous or intermittent

An example of the rating scheme is shown below in tabular format. The task, install drywall, is broken into the four steps that one or more crew members would normally perform: measure the wall and mark the drywall panel, cut the drywall panel to the correct size, move the panel into position, and finally screw the panel to the framing members.

Task	Generic Risk Factors for Overexertion Injuries						
Install drywall	Repetitive exertions	Static exertions	Forceful exertions	Localized mech. stresses	Posture stresses	Low temp.	Vibration
Measure wall and mark panel	1	1	1	1	1	1	1
Cut drywall panel	2	1	2	1	2	1	1
Move panel into position	1	3	3	2	3	1	1
Screw panel to studs	3	1	2	1	2	1	3

The task, install drywall, is chosen as an individual task, because that is the normal cycle that a crew would perform over and over for an extended period of time. The construction of the framing members to which the drywall panel is attached, would be a separate task, because normally a different crew would construct all the partition frames at one time, before the drywall hanging crew started its work. Once the drywall panels are installed, another crew would begin taping or finishing the joints. This is a totally separate operation from constructing the frames and hanging the panels. Of course the three tasks are related, but normally three separate crews are involved at three different times. It is reasonable to expect that the different crew members will be exposed to different types of overexertion injuries because each crew performs fundamentally different work.

Rating every step of every task that construction craft workers perform may, at first, appear to be an overwhelming project. By analyzing the work at the Basic Task level of detail (Everett 1990, 1991), the scope of the project becomes much more manageable. Each step in the drywall hanging task corresponds to one of twelve Basic Tasks: Connect, Cover, Cut, Dig, Finish, Inspect, Measure, Place, Plan, Position, Spray, and Spread. Measure wall and mark panel corresponds to the basic task Measure, cut drywall panel corresponds to Cut, move panel into position corresponds to Position, and screw panel to studs corresponds to Connect.

Every step of every construction task can be matched with one of the twelve Basic Tasks. Many construction operations follow the same general sequence as installing drywall: measure or layout the work; cut, finish or otherwise process a component to be assembled;

place or position the component to its final location; and connect the component to other components already constructed.

Many other construction operations consist of just one Basic Task after a brief period of preparation. For example, once a painter gets set up to paint with a brush or roller, he/she can paint or Spread for hours. Drywall finishers spend virtually all of their time either Spreading joint compound or sanding/Finishing joints.

Whether a screw gun is used to attach drywall to studs, or plywood to joists, or light fixtures to ceilings, the craft worker is exposed to vibration. Whether a drywall finisher bends over to tape a joint, or an ironworker bends over to weld a shear stud, or a laborer bends over to pick up trash, all are exposed to awkward postures and risk of back injury. Whether a tile setter kneels down all day to set ceramic tile, or a cement finisher kneels down to trowel concrete, or a carpet installer kneels down to lay carpet, all are exposed to similar knee and back postures.

After analyzing several tasks, it should become apparent to the craft workers providing input how similar the ergonomic stresses of analogous Basic Task components of their work are, even if the overall operations and finished product seem completely different.

Those tasks or steps with tasks that have unusually high risks of overexertion injuries will be identified by their high scores in the analysis for generic risk factors. In many cases, it may be obvious which tasks place craft workers at high risk, but there may be one or two steps in a complex process which contribute most of the hazard. In the drywall installation example above, measuring the wall and marking the wall appear to be relatively free from risk factors. Positioning the panels induces high levels of forceful and static exertions and large posture stresses. Screwing the panels to the studs involves high repetitions and high levels of vibration.

Rather than attempting to redesign drywall hanging in general, or building complex automation and robotic hardware to perform all of the steps in the hanging process, it may be more appropriate to focus on a few specific aspects of the work. For example, using adhesives instead of screws may eliminate some or all of the hazard of screw gun operation. Developing or purchasing a vibrationless screw gun may also be a feasible alternative to current practice. Automated positioning and connecting devices might also be used.

The implications of this research upon the construction automation and robotics R&D community is to provide a basis for prioritizing tasks for application of new technology. Factors to be considered include: 1. The number of craft workers assigned to the task and the number who might benefit directly from automation and robotics; 2. The time required to develop and implement new automation and robotics technologies. Initially, jobs where changes can be implemented quickly will have high priority; 3. The cost of the change. In general, changes that have low costs will be of higher priority than high-cost changes. However, this rule will not be absolute; and 4. The technical feasibility of the change. Changes that require major technological interventions would have lower priority than changes that can utilize "off-the-shelf" technology.

CONCLUSION

Overexertion injuries are the single largest classification of injury in construction in the United States, accounting for about 24% of all injuries. Overexertion injuries generally occur as a result of performing a given task as planned. While overexertion injuries are not intentional, the underlying causes of the injuries are built into the prescribed tools and work methods. This paper has described a current research project that analyzes construction tasks for the presence of seven generic risk factors for overexertion injuries. High risk tasks can then be targeted so that automation, robotics, and ergonomic principles can be applied to modify the task or work environment to accommodate human capabilities and limitations.

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