110

Ergonomics in the Construction Industry

Scott P. Schneider*
The Center to Protect Workers' Rights

110.1 Introduction — The Size and Scope of the Problem

There is substantial evidence that musculoskeletal injuries are a major problem in the construction industry (Schneider, 1997a). The lost-time injury rate for "sprain and strain" injuries in construction is about 50% higher than that in manufacturing and second only to the rate for the transportation industry. In 1995, the construction rate was 158.7 lost workday cases per 10,000 full-time workers, or about 1.6 cases per 100 workers (BLS, 1997). The rate in private industry overall was 107.5 cases per 10,000 workers. While this rate dropped in 1995 by almost 12% from 1994, the rate is still very higher and much higher than other industries. The rates for cumulative trauma disorders, like carpal tunnel syndrome and tendonitis, on the other hand, tend to be much lower in construction than in manufacturing industries, most likely due to increased awareness in manufacturing and, perhaps, to the less repetitive nature of construction work, in general. In 1995, the rate of lost workday injuries for carpal tunnel was only 2.8 cases per 10,000 full-time workers, compared with 8.0 in manufacturing and 3.9 in all private industry. The 1995 rate for tendonitis was 2.1 for all construction, 5.5 for manufacturing, and 2.7 for all private industry.

110.2 Using Surveillance Data to Identify High-Risk Trades

While construction work, in general, is risky for musculoskeletal injuries, the industry is diverse and the risks vary depending on the trade and the type of work done by that trade. BLS Annual Survey data show the roofing, siding, and sheet metal industry to have the highest risk of sprains and strain lost workday injuries (234.2 per 10,000 in 1995), followed by masonry contractors (202.4) and plumbing and heating

* Currently with the Laborers' Health and Safety Fund of North America

0-8493-2641-9/99/$0.00+$.50

(190.8). Painting and electrical contractors had the lowest lost workday injury rates in construction for sprains and strains in 1995 (128.0 and 125.2, respectively). Rates for carpal tunnel syndrome and tendonitis also varied dramatically, with carpenters having the highest rate of carpal tunnel lost workday injuries (12.1 per 10,000) and masonry contractors having the highest rate for tendonitis (7.8 per 10,000).

Hsaio and Stanevich (1996) analyzed workers' compensation data from 21 states in 1987 (the BLS Supplementary Data System) to rank construction occupations in terms of injury risks to set priorities for future research and interventions. They identified construction laborers, carpenters, roofers and drywall installers as the four highest risk construction occupations. Overexertion injuries were the most common injury type for construction laborers, drywall installers, plumbers, electricians, and structural metal workers, (representing about 22 to 29% of injuries) and the second most common injury for roofers and carpenters.

Analyses of workers' compensation data from Washington state also show construction occupations to be risky in terms of musculoskeletal disorders (WA DL&I, 1996), showing wallboard installation, roofing and concrete construction to be three of the top 10 occupations in terms of incidence rates (first, third, and tenth, respectively).

Surveys of musculoskeletal symptoms among construction workers also show different prevalence patterns among different construction trades (Cook et al., 1996a; Engholm et al., 1997; Holmström et al., 1995, Rosecrance et al., 1977; Zimmermann et al., 1997a). Knee injuries are highest among plumbers, roofers, floorlayers, and sheet metal workers whose jobs require a lot of kneeling. Shoulder problems are most common among scaffold erectors, insulators, and painters who have to work overhead a great deal. Low-back problems are common among most trades, but highest among roofers, floor layers, and scaffold erectors who have to do a lot of heavy-materials handling and stooping. Bricklayers have high rates of elbow and shoulder symptoms apparently because of the awkward postures during work (Cook et al., 1996b). Operating engineers, who operate heavy equipment, had the lowest rates of musculoskeletal symptoms because of the nature of their work, primarily sedentary (Zimmermann et al., 1997b). These trade-specific profiles should be helpful in identifying high-priority trades and areas for intervention.

110.3 The Risk Factors Associated with Different Trades

Certain construction trades have been extensively studied while others have not. Some trades are easier to study in that they perform a more limited number of tasks, like bricklayers and concrete reinforcement workers. Other trades, like carpenters and construction laborers, perform a wide variety of work and only certain subtrades, like drywall installers, have been well studied. Table 110.1 summarizes the state of research on ergonomic problems in the construction trades (CPWR, 1996).

For most trades, there is substantial information of the types of musculoskeletal injuries occurring in that trade. For many of the trades there has been a delineation of the tasks they perform, and high-risk tasks have been identified. Interventions have been identified for some trades, but few have been evaluated. The largest problem remaining for research is identifying the barriers to adoption of these interventions and how these barriers could be overcome.

Trades that have been thoroughly studied include: concrete reinforcement workers (rodmen) (Saari et al., 1978; Wakula et al., 1997), bricklayers (Cook et al., 1996b; Schierhorn, 1996), carpet layers (Thun et al., 1987; Tanaka et al., 1989), operating engineers (Zimmermann, 1997b).

110.4 Exposure Assessment for Ergonomic Risk Factors in Construction

Most ergonomic exposure assessment for exposure to risk factors has taken place in industries where workers have relatively short cycle jobs, like assembly line work. Recently though there has been a growing interest in looking at long cycle jobs, like those in construction. The approach has generally been to look at the risk factors for individual tasks and either sum up the stresses based on estimates of time spent in the task or use the information to prioritize tasks for intervention. Systems that have been adapted or

TABLE 110.1 Status of Research on Ergonomic Problems in Construction by Trade

Trade	WMD	Tasks	Hi Risk	Intervention	Barriers
Bricklayers	√	√	√	√	*
Carpenters					
drywall	√	√	√	√/*	*
concrete form	√	√	√	*	*
frame	√	*	*	*	*
finish	√	*	*	*	*
pile driver	*	*	*	*	*
ceiling	√	√	√	*	*
tile, terrazzo	*	*	*	*	*
lather	*	*	*	*	*
cabinetmaker	*	*	*	*	*
scaffolder	√	√	√	*/√	*
carpet/floorlayer	√	√	√	*/√	*
diver	*	*	*	*	*
exhibit	*	*	*	*	*
millwright	*	*	*	*	*
maintenance	√	*	*	*	*
Cement Masons	√	√	*	*	*
Electricians	√	*	*	*	*
Elevator Constructors	*	*	*	*	*
Insulators	*	*	*	*	*
Ironworkers					
structural	√	√	*	*	*
rodmen	√	√	√	*/√	*
ornamental	*	*	*	*	*
shop	*	*	*	*	*
Laborers	√	*	*	*	*
Operating Engineers					
operators	√	√	√	√	*
stationary	*	*	*	*	*
Painters	√	*	*	*	*
carpet/floorlayer	√	√	√	*	*
glaziers	*	*	*	*	*
Plasterers	√	√	*	*	*
Plumbers	√	√	*	*	*
Pipefitters	√	√	*	*	*
Roofers					
residential	√	*/√	*/√	*	*
commercial	√	*/√	*/√	*	*
Sprinklerfitters	*	*/√	*/√	*	*
Sheet Metal					
shop	*	√	*	*	*
field	√	√	*	*	*
Teamsters	*	*	*	*	*

* = needs more research
√ = unknown

created for ergonomic exposure assessment in construction include the OWAS method (Kivi and Mattila, 1991; Mattila et al., 1993), ARBAN method (Wagenheim et al., 1986), PATH method (Buchholz et al., 1996), and MAS method (Schildge et al., 1997; Wakula et al., 1997). These methods tend to estimate the percentage of time spent in awkward postures during given tasks. Time spent in a task is estimated by diaries, self reports, or expert observers. Studies are now under way to validate these methods against more quantitative methods, like dosimeters. Checklists for exposure assessment in construction are also being studied (Everett, 1997; Buchholz et al., 1996). Exposure assessment in construction is still at an early stage. Its importance will grow, particularly as a tool to measure the efficacy of interventions.

110.5 Types of Interventions in Construction

Ergonomics has often been associated with manufacturing and office work environments. Consequently, consideration of ergonomics in construction appears disconcerting. Contractors and workers seem to believe that construction work is hard manual labor and there's nothing that can be done to change it. This is despite the evidence of how the work has actually changed over the past 10 to 15 years. Construction work, while it hasn't become automated like assembly line work, has become more mechanized. More and different kinds of equipment are now used on job sites to move materials and to do some of the heavy work. Hoists and cranes are commonly used for materials handling. Boom trucks are used to lift materials to roof level. Scissors lifts are commonly used to move workers up to work at heights. Motorized buggies are used to move materials around on sites. Powered equipment like roof cutters, powered brooms and gravel removal equipment, and powered roof tear-off equipment all have reduced the risk of strains and sprains in roofing tear-off work. Asphalt is now pumped to the roof rather than being mixed in small batches in a kettle. Circular saws, powered screw guns (battery-operated), and pneumatic nail guns have made carpenters' work easier. Robots even exist now for doing demolition work. Yet even with this new equipment there is still a high risk of injury and a significant amount of manual work and work in awkward postures. In some cases the contractors are too small to afford or use such equipment. In other cases, the demands of a particular job may not allow their use. In addition, many jobs cannot be mechanized.

Ergonomic interventions in construction don't all revolve around mechanization or automation. In fact, most "ergonomic" changes in construction involve little more than proper planning of the job.

Interventions to reduce the risk of musculoskeletal disorders in construction can be classified as follows: (A) new materials, (B) new tools and equipment, (C) improved work practices, (D) improved work organization and planning, (E) education and exercise, and (F) personal protective equipment.

A) New materials. Construction materials have changed over the past few decades. Drywall has essentially replaced plaster walls. Poured concrete has replaced a lot of brick walls. Many sections of houses now come prefabricated. Sometimes the changes are beneficial from an ergonomic point of view. Other times they trade one hazard for another. Drywall work, as mentioned earlier, is one of the most hazardous trades in construction for musculoskeletal injuries. The trend in newer materials can be useful when lighter-weight materials are designed. For example, the Army Corps of Engineers worked with the University of Nebraska to design a new masonry block, the Nebraska A block, which is half the weight of a traditional block but just as strong (Hooker, 1996). Another solution instituted in Germany was the design of a new masonry block that has hand holds to make it easier to handle (Kaiser and Linke-Kaiser, 1992). The weight and the diameter (normally 4 ft) of drywall makes its use hazardous. In Sweden, the industry has been promoting the use of 3 ft wide (90 cm) drywall boards, which are easier to install than the larger size, but consequently increase the amount of drywall taping and screwing required. (Isakson et al., 1992; Björklund et al., 1991). The use of fiberglass ladders reduces the weight of handling compared with wood ladders. Plastic pipe has also reduced the weight of materials for plumbers.

B) New tools and equipment are constantly being invented to make construction work easier. Tool catalogues from tool suppliers and trade publications are a good source for keeping up with such tools. These tools are designed to reduce the need for bending, e.g., allow for work from a standing height, like guns for fastening roofing insulation and automatic feeding screwguns for fastening flooring. Hand tools can reduce the stress on the hand by having softer, easier-to-hold surfaces. Handles are available to make carrying materials easier. Carts and dollies can be used to help move materials around a site and reduce the need for manual handling. Pulleys and hoists make it easier to lift materials. Stands, like pipe stands, can be used to bring work to waist height. Sit-stand stools or matting can reduce the risk of back injury from standing on concrete all day (Redfern, 1995). Racks can be used for storing materials at waist height.

Power tools can be purchased with vibration dampening to reduce the amount of vibration transmitted to the hands. Construction vehicles now have better-designed cabs available which are more comfortable and reduce the transmission of whole-body vibration through the seat. Many of the best tools have been designed or invented by tradespeople who felt they needed something new to do the job right or easier

(Wigmore and Moir, 1997). The proper design of tools requires usability testing with tradespeople to understand the way tools are used in the field and the demands placed on them by workers (Bobjer and Jansson, 1997). The design of any new tool or equipment should include an evaluation to demonstrate reduced risk of injury or, at least, a reduction in risk-factor exposure.

C) Improved work practices involve changing how the work is done. By substituting a scissors lift for a ladder, workers can get to overhead work more easily and position themselves closer to the work, requiring less work with arms above shoulder level. Getting two workers to carry drywall (e.g., using drywall handles on the front and back) or relying on carts and dollies can reduce the risk of injury from materials handling. For those tasks where manual handling is unavoidable, teaching better work technique is important. For example, lifting heavy bags from ground level should be done from a kneeling position by sliding the bag onto the knee and then standing. Drywall boards should first be tipped on end before being picked up (CSAO, 1991). Studies have shown that work technique of older, experienced workers may be more efficient and ergonomically preferable than those of apprentices or novices (Authier et al., 1996). Training in these techniques could help reduce the risk of musculoskeletal injuries although it is unclear at this point how effective such training is.

D) Improved work organization means changing the way the work is organized to reduce the risk of injury. The foreman and superintendent on a job have a major role to play in the proper planning of the job to make sure it gets done on time and gets done safely. Through proper planning these two goals can complement each other. They need to make sure that materials are delivered on time and as close to the work area where they will be used as possible. They also want to avoid ordering or delivering too much material at once which leads to problems with storage and a cluttered worksite. They need to make sure work is done by the various subcontractors on time in order to not delay the subsequent contractors and place them under heavy production pressures to catch up. A Swedish project called "Building for the 21st Century" has called for bringing workers into the production planning process as the best method to improve planning and reduce production pressures (Kortabyggtider).

Sufficient helpers, apprentices or materials handlers should be available to make sure workers are supplied with the materials and equipment they need when they need it. They need to ensure the availability and usability of materials handling devices (carts, dollies, hoists, cranes). Crane time can sometimes be at a premium and proper scheduling of crane time can significantly reduce manual materials handling. A proper break schedule is also critical. Insufficient rest breaks lead to fatigue and reduce productivity as well as increasing risk of injury. In addition to scheduled rest breaks, short mini-breaks (e.g., 30 second "micropauses") have been shown to reduce fatigue and increase productivity in drywall installers (Anderson, 1991). Piece rate work has been shown to be a risk factor for musculoskeletal injuries (Brisson et al., 1989). In construction, drywall installation is one of the few jobs which is commonly paid on a piece rate. This may be one reason it has one of the highest risks for injury. The distribution of workload is another important work organization issue that needs to be addressed.

Improved housekeeping has also been shown to be related to reduced risk of injury (Oxenburgh, 1991). This is an important work organization issue, because it requires the cooperation and coordination of all subcontractors on the site. Superintendents must make clear that each subcontractor is responsible for their own housekeeping to avoid creating a hazard for others. Sometimes they take on more responsibility and develop joint clean up crews to organize housekeeping on a site-wide basis.

Job rotation, e.g., rotating workers between physically demanding and less physically demanding jobs, can sometimes be done in construction. In addition teaming of workers who can often rotate tasks is possible. Another concern is that often young workers carry a disproportionate amount of the heavy work on a site. This increases their risk of injury, particularly the chronic injuries that will accumulate later in life. While the heavy work cannot be redistributed to the older or less physically capable workers, they need to be sensitive to not straining or pushing the younger workers too hard. By reducing the workload for all workers, the work can be distributed more evenly and more fairly.

Architects and engineers also have a major role to play upstream, while the project is being designed. By specifying lighter-weight materials, e.g., 3-foot-wide drywall, they can reduce the load on the construction workers. In Sweden, designers placed pipes on the wall of a utility tunnel instead of overhead, reducing the amount of overhead work (Björk, 1984). The more ergonomics can be considered in the design of buildings, the less we have to rely on *post hoc* changes as the building is being built. Superintendents and foremen also need to structure the job so that issues of ergonomics can be incorporated into their regular safety program and walk arounds. A construction ergonomics checklist has been designed specifically to get safety personnel thinking about ergonomic issues on their worksite (CPWR, 1997).

E) Education and exercise have also been suggested as effective interventions for ergonomic risk factors in construction. Ergonomics training is becoming more common in the construction trades. The Carpenters Union has developed a half-day training program on ergonomics for carpenters which is given through their apprenticeship schools (UBC Safety & Health Fund, 1996). The Building Trades Department of the AFL-CIO is developing a training module on ergonomics to be given to all apprentices as part of their safety training. Contractors who do ergonomics training tend to focus on proper lifting technique and stretching exercises, while these new training programs focus on identification of risk factors and problem solving to identify potential solutions. They also tend to include more participatory training techniques, where workers are active participants in the learning process, which appear to be more effective and allow workers to share their knowledge of conditions and experiences in crafting solutions (Shurman et al., 1994).

Labeling of the weights of materials to be manually handled may also help reduce the risk of musculoskeletal injuries (Butler et al., 1993). It has been suggested that construction materials be labeled where possible with the weight and color coded labels to indicate if it was safe to lift manually or alone (Schneider, 1994a).

Exercise or stretching programs have become popular among construction contractors over the past few years. They operate on the assumption that by stretching the muscles and tendons prior to work, they can better adjust or acclimate to the stresses placed on them later in the day. There have been two evaluations done on stretching programs in the construction industry, one in Sweden and one in the U.S. (Cederqvist 1994; Hecker and Gibbons, 1997). Both were surveys of workers involved in a pre-job stretching program. Both found positive results. Workers who did the stretching exercises liked them and felt that they helped in reducing fatigue and increasing awareness of ergonomic risk factors. In general they felt better at the end of the day. A large percentage also continued doing the exercises on weekends and said they would continue doing them on their next job. While this doesn't necessarily translate into lower injury rates, these positive indicators are some support for continuing these programs and further evaluation of their impact.

F) Personal protective equipment (PPE) is normally the last resort in terms of intervention strategies. It allows the continued presence of a risk factor and the worker must rely on the proper use of a device to intervene and modify the effect of the exposure. This is a less reliable strategy. Yet in construction, there are several instances where PPE can be necessary. While some work can be modified to allow work to be done from a standing height, there will still be some work required at floor level. Kneeling will have to be done at some point. Large amounts of time spent kneeling has been correlated with knee disorders. So clearly knee pads can play an important role in prevention of knee disorders in construction. The problem is that workers don't like to wear knee pads. The straps used to keep them on bind against the back of the legs and make them uncomfortable to wear. One possible solution is pants with knee pad pockets in front of the legs. Shoulder pads are also available for construction workers who have to carry materials on their shoulder, where contact stresses can pinch nerves and tendons and contribute to shoulder disorders. There are also shoe insole pads designed to reduce stress on the back for those workers who have to walk around all day on concrete.

The most controversial protective equipment issue in ergonomics for construction workers is the use of back belts. During the 1990s they have become increasingly popular among contractors. Yet there is little evidence to support their use in preventing back injuries in the first instance (NIOSH, Back Belt Working Group, 1994), although a recent study indicated they may have some efficacy (Kraus et al., 1996). If they are used, use should be voluntary and should be accompanied by an education and training program on proper use. They should also be used under the supervision of a physician who can certify that workers are fit to wear them. It should be emphasized that use of the belt does not allow a worker to lift more then they normally would. They should only be considered a supplement to a complete ergonomics program and not a substitute for one. There should also be a program of quality assurance to make sure people are using the belts properly.

110.6 Introduction and Implementation of Interventions in Construction

While there are many potential ergonomic interventions in construction, few have been adopted. Making ergonomic changes in construction is difficult, but there are many possible interventions (Schneider, 1995; Schneider et al., 1995). The construction industry is inherently conservative. Workers tend to be individualistic and safety culture is difficult to change. This is in part due to the nature of the work, where workers are changing jobs frequently and may also change employers. Ergonomic challenges also change as the job site changes. There are four different levels of ergonomic changes available in construction: industry-wide changes, company-wide changes, site-specific changes, and changes on the individual level (Schneider, 1996b). Industry-wide changes include: development of new ergonomically designed tools, changes in materials used (e.g., switching to 3-ft-wide (90 cm) drywall), and availability of new equipment (e.g., adjustable height scaffolding). These changes are the most difficult to accomplish, because of the investment required for the development of new tools and equipment and the level of proof required before contractors will adopt new methods. Company-wide changes depend primarily on individuals in authority within those companies who have the vision or commitment to safety and are willing to try out changes. Site-specific changes depend on the job superintendent, if he or she is willing to try out new methods and chance their potential impact on the production schedule. Sometimes change on an individual site depends as well on the owners of the project. If they are open to new methods and willing to pay for interventions (which hopefully will result in some payback in less lost work time and injuries), then superintendents are willing to go along with such programs. Changes on the individual level are the most difficult to sustain in that each individual's behavior must be changed and monitored. Workers who have been doing a job one way for many years are often reluctant to change. Such changes are most effective when introduced early in their careers when they are learning as apprentices. But teaching a person how to lift heavy materials properly doesn't solve the problem the way a foreman or superintendent can, by ensuring carts or dollies are available and in good working order or by ensuring that materials are delivered as close as possible to where they will be used. Also the fundamental problems posed by poor planning can only be solved by superintendents, working in conjunction with the workers, on a site-wide level. Changes on the site-wide or company-wide level have much more potential for reducing the risk of injury than individual changes.

There are numerous problems in making changes in construction. If changes are primarily motivated by the need to save money and the promise of increased productivity, workers may be resistant to changes, since higher productivity means doing more work with fewer workers. This is also true if changes, in making the jobs easier, also deskill the work. Lower skill required often means less pay for workers, which means workers can be expected to resist these changes as well. Recently, several participatory ergonomic projects have been tried in construction with great success (Bronkhorst et al., 1997; van der Molen et al., 1997b; Moir, et al., 1996). Workers have been included in the process of identification of high-risk tasks and potential solutions. Projects have led to the development of successful interventions for scaffold erectors, glaziers, and other trades. By including workers in each phase of the process, acceptance of interventions and changes is much easier.

110.7 Regulatory Standards

Another way to effect change in an entire industry is through regulation. For the past several years the federal government has been working on the development of an OSHA standard for the prevention of musculoskeletal injuries. A draft of this proposed standard was circulated in March 1995. The OSHA Advisory Committee for Construction Safety and Health (ACCSH) set up a work group which reviewed the draft and proposed changes to make it more useful in construction (Schneider, 1996a). Because of Congressional restrictions, a proposed standard cannot be issued before October 1998, and it is unlikely that the initial proposal will cover construction.

In 1997, California OSHA promulgated a standard for the prevention of cumulative trauma disorders. While this standard would have exempted much of the construction industry, because it exempted employers with nine or fewer employees, the California Supreme Court struck down that provision in September 1997.

In the meantime, the U.S. Army Corps of Engineers, one of the largest construction employers in the U.S., issued a "cumulative trauma prevention "standard in September 1996 which applies to all contractors doing work for the Corps (Schneider, 1997b). It is a programmatic standard requiring job hazard analyses before each job to identify potential ergonomic risk factors and potential solutions to be instituted. Workers must get ergonomic training. Contractors must also reduce vibration exposures to below the ACGIH TLV.

The ASC Z 365 committee is finalizing its draft standard for the prevention of cumulative trauma disorders of the upper extremity, which would also apply in the construction industry. It was approved in Spring 1998. While this is a voluntary standard, these standards do set some minimum expectations with regard to safety programs which often become industry-wide standard practice. This draft standard is also a programmatic one which requires employers to identify high-risk jobs or tasks, develop potential solutions, implement and evaluate those solutions, and develop a medical management program for injured workers to help them return to work (Armstrong, 1997).

Other countries have developed or implemented standards to prevent musculoskeletal injuries in construction. Germany and Sweden have issue rules limiting the weight of masonry blocks that can be lifted manually (Swedish Standards, Kuger et al., 1992). (Masonry union contracts in the U.S. also contain weight limits for blocks that can be lifted by one person.) In The Netherlands, the Stichtung Arbouw (a joint labor–management group) has developed "Guidelines for Physical Workload in the Construction Industry" which contain limits on lifting, carrying, pushing and pulling, static postures, and repetitive work. The guidelines prescribe red (interventions required), yellow (interventions should be planned), and green (permissible) levels of effort (Stichtung Arbouw, 1997, van der Molen, 1997a).

110.8 Conclusion

Musculoskeletal injuries are a major problem in the construction industry. They constitute a large percentage of the lost workday injuries and workers' compensation cases and costs. They also result in shortened careers for many construction workers. Ergonomics is the process by which these injuries can be addressed and many of them prevented. High-risk trades can be identified through injury and symptom surveillance and associated with specific types of injuries. High-risk tasks can be identified though observations and focus groups of workers and through quantitative measurements of exposures to well-known risk factors, like awkward postures. A wide range of interventions are available, although few have been tested for efficacy. Interventions include: materials handling equipment, improved tools, new work methods, better work organization and planning, worker training, exercise programs, and personal protective equipment. The most effective strategies are those which effect change in the design of the work and those which include workers in each and every step of the process (a participatory ergonomics program). There are several recent examples of such successful projects in the construction industry. But change in the construction industry is difficult. There has to be a an acknowledgment of the problem and a willingness to try new ideas and techniques, even though they may not prove effective. But those firms which are committed to attacking this problem properly will find a great potential for success.

Acknowledgments

This research was funded through a cooperative agreement (# CCU/02-312014) from the National Institute for Occupational Safety and Health (NIOSH) to the Center to Protect Workers' Rights (CPWR), the research arm of the Building and Construction Trades Department of the AFL-CIO.

References

Anderson, P: Manual screw tightening with and without micro pauses, *Bygghälsan Bulletine*, 91-09-16, 39-40, 1991.

Armstrong, T: Development of a voluntary standard for the control of work-related cumulative trauma disorders in the United States: ANSI Z365, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, Tampere, Finland, 3: 483-485, 1997.

Authier, M; Lortie, M; Gagnon, M: Manual handling techniques: comparing novices and experts, *International Journal of Industrial Ergonomics*, 17: 419-429, 1996.

Björk, L: Survey of working environment in the plumbing sector, *Bygghälsan Bulletine*, 1984-09-01, pgs. 4-5, 1984.

Björklund, M; Helmerskog, P.; Nordberg/Bohlin, M. et al.: 90-sheets for the 90s, *Bygghälsan Bulletine* 91-09-16, pgs. 35-36, 1991.

Bobjer, O; Jansson, C: A research approach to the design of ergonomic hand tools. The 11-point approach, *Proceedings of 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, Tampere, Finland, 2: 193-195, 1997.

Brisson, C., A. Vinet, M. Vézina, S. Gingras. Effect of duration of employment in piecework on severe disability among female garment workers. *Scandinavian Journal of Work, Environment and Health*, 15:329-334, 1989.

Bronkhorst, RE; Vink, P; Koningsveld, EAP: Ergonomic improvements for the glazier — new working methods and tools do improve the working conditions, *Presentation to the 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, Tampere, Finland, 1997.

Buchholz, B; Paquet, V.; Punnett, L; Lee, D; and Moir, S; PATH: A work sampling-based approach to ergonomics job analysis for construction and other non-repetitive work, *Applied Ergonomics*, 27(3): 177-187, 1996.

Bureau of Labor Statistics (BLS), Data from the 1995 Annual Survey of Occupational Injuries and Illnesses, Data obtained from BLS Website (http://www.bls.gov).

Butler, D.; Andersson, GBJ; Trafimow, J; Schipplein, OD; Andriacchi, TP: The influence of load knowledge on lifting technique, *Ergonomics* 36 (12): 1489-1493, 1993.

Cederqvist, T: Prevention of musculo-skeletal injuries in the swedish construction industry- experience from five years of a pre-work warm-up program, *Proceedings of the 12th Triennial Congress of the International Ergonomics Association*, August 15-19, Toronto, Canada, 2: 60-62, 1994.

Center to Protect Workers' Rights, (CPWR). *Construction safety and health research: five years of progress and proposals for the future* — Report of the CPWR-NIOSH Program Planning Conference *Joint Strategies to Advance Research in the Construction Industry*, Cincinnati, OH April 1–2, 1996.

Center to Protect Workers' Rights, (CPWR). "Construction Ergonomics Checklist," 6 pages, 1997.

Construction Safety Association of Ontario (CSAO), *Stand, Lift, Carry*, Revised, 1993 edition, 41 pages, Toronto, Ontario.

Cook, TM; Rosecrance, JC; Zimmermann, CL: *The University of Iowa Construction Survey*, The University of Iowa and the Center to Protect Workers' Rights, Washington, D.C. April 1996a.

Cook, TM; Rosecrance, JC, Zimmermann, CL: Work-related musculoskeletal disorders in bricklaying: a symptom and job factors survey and guidelines for improvement, *Applied Occupational and Environmental Hygiene*, 11 (11): 1335-1339, November 1996b.

Engholm, G; Holmström, H: Physical exposures, psycho-social factors and patterns of prevalence of musculoskeletal disorders in various groups of swedish construction workers, Presentation to the 13th Triennial Congress of the International Ergonomics Association, June 29–July 4, Tampere, Finland, 1997.

Everett, JG: Application of U.S.A. OSHA Draft Ergonomic Protection Standard to Construction Tasks, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association,* June 29–July 4, Tampere, Finland, 6: 93-95, 1997.

Hecker, S; Gibbons, B: Evaluation of a prework stretching program in the construction industry, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association,* June 29–July 4, Tampere, Finland, 6: 115-117, 1997.

Holmström, E; Ulrich Moritz; Engholm, E: Musculoskeletal disorders in construction workers, *Occupational Medicine: State of the Art Reviews,* 10(2), April 1995, pgs. 295-312, *Construction Safety and Health,* Eds. K. Ringen, A. Englund, L. Welch, J. Weeks and J. Seegal, Hanley & Belfus, Philadelphia, 1995.

Hooker, KA: Specialty block for special uses, *Masonry Construction* 9(5): 198-201, May 1996.

Hsaio, H; Stanevich, RL: Injuries and ergonomic applications in construction, Chapter 27, Pgs. 545-568 in *Occupational Ergonomics: Theory and Applications,* Eds. A. Bhattacharya and J.D. McGlothlin, Marcel Dekker, New York, 1996.

Isakson, H; Kling, J.: Fitting 900mm and 1200 mm plasterboard sheets, *Bygghälsan Bulletine,* 91-09-16, pgs. 37-38, 1991.

Kaiser, R. and G. Linke-Kaiser: Verbesserung der Arbeitsbedingungen im Mauerwersbau *ErgoMed,* 16: 14-25, 1992.

Kivi, P; Mattila, M: Analysis and improvement of work postures in the building industry: application of the computerised OWAS method, *Applied Ergonomics,* 22(1): 43-48, 1991.

Kortabyggtider, Building for the 21st Century: Results from the Development Programme Tight Construction Schedules, a publication from a joint employer-employee working group in Sweden.

Kraus, JF; Brown, KA; McArthur, DL; Peek-Asa, C; Samaniego, L; Kraus, C: Reduction of acute low back injuries by use of back supports, *Int J Occup Environ Health,* 2: 264-273, 1996.

Mattila, M; Karwowski, W; Vilkki, M: Analysis of working postures in hammering tasks on building construction sites using the computerized OWAS method, *Applied Ergonomics,* 24(6): 405-412, 1993.

Moir, S; Buchholz, B: Emerging participatory approaches to ergonomic interventions in the construction industry, *Am. J. Industrial Medicine,* 29, 425-430, 1996.

NIOSH Back Belt Working Group, *Workplace Use of Back Belts: Review and Recommendations,* National Institute for Occupational Safety and Health, Centers for Disease Control, U.S. Department of Health and Human Services, July 1994.

Oxenburgh, M: *Increasing Productivity and Profit through Health and Safety,* CCH International, Chicago, 309 pgs., 1991.

Redfern MS: Influence of flooring on standing fatigue, *Human Factors,* 37(3): 570-581, 1995.

Rosecrance, JC; Cook, TM; Zimmermann, CL: Work-related musculoskeletal symptoms among construction workers in the pipe trades, *Work,* 7: 13-20, 1996.

Saari, J. and G. Wickström: Load on back in concrete reinforcement work, *Scan. J. Work Environ. Health,* 4 suppl. 1: 13-19 (1978).

Schierhorn, C: Jobsite ergonomics, *Masonry Construction,* 9(5): 202-207, May 1996.

Schildge, B; Wakula, J; Rohmert, W.: Ergonomic Analysis of load on the knees at the tile-setter's work, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association,* June 29–July 4, Tampere, Finland, Volume 6: pgs. 163-165, 1997.

Schneider, S., Musculoskeletal injuries in construction: are they a problem?, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association,* June 29–July 4, Tampere, Finland, Volume 6: pgs. 169-171, 1997a.

Schneider, S, The U.S. Army Corps of Engineers ergonomics standard, *Applied Occupational and Environmental Hygiene*, 12(7): 460-461, July, Ergonomics Column, 1997b.

Schneider, S., OSHA's draft standard for the prevention of musculoskeletal disorders: the construction revision, pp. 953-955, *AIHA Journal*, 57 (10), October 1996a.

Schneider, S., CYBERG 96 paper, September, *Making Ergonomic Changes in Construction*, 1996b.

Schneider, S., "Implement ergonomic interventions in construction, *Applied Occupational and Environmental Hygiene*, 10(11): 822-824, October, Ergonomics Column, 1995.

Schneider S., Punnett L., and Cook T, Ergonomics: applying what we know, in *Construction Safety and Health*, in the *Occupational Medicine: State of the Art Reviews* series, Vol. 10 (2):385-394, Eds. K. Ringen, A. Englund, L. Welch, J. Weeks and J. Seegal, Hanley & Belfus, Philadelphia, 1995.

Schneider, S., Ergonomic safety data sheets, *Applied Occupational and Environmental Hygiene*, 9(6): 402-403, June, Ergonomics Column, 1994a.

Schneider, S. and Susi, P., Ergonomics and construction: a review of potential hazards in new construction, July 1994, *American Industrial Hygiene Association Journal*, 55 (7): 635-649, 1994b.

Shurman, S; Silverstein, BA; Richards, SE: Designing a curriculum for healthy work: reflections on the United Automobile, Aerospace and Agricultural Implement Workers — General Motors Ergonomics Pilot Project, *Occupational medicine: State of the Art Reviews*, 9(2): 283-304, 1994.

Stichtung Arbouw, *Arbouw Foundation Guidelines on Physical Workload for the Construction Industry*, Amsterdam, May 1997, 19 pgs.

Swedish Standards for Masonry Block Work (Svenska Standard SS 22 72 30), Swedish Ministry of Labour.

Tanaka, S., S.T. Lee, W.E. Halperin, M. Thun, and A.B. Smith: Reducing knee morbidity among carpetlayers, *Am. J. Public Health*, 79(3): 334-335, 1989.

Thun, M., S. Tanaka, A.B. Smith, W.E. Halperin, S.T. Lee, M.E. Luggen, and E.V. Hess: Morbidity from repetitive knee trauma in carpet and floor layers. *Br. J. Indus. Med.*, 44: 611-620, 1987.

UBC Safety and Health Fund of North America, *Ergonomics for Carpenters*, Washington, D.C., 88 pgs., 1996.

van der Molen, HF, and Delleman, NJ, Arbouw guidelines on physical workload for the construction industry, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, Tampere, Finland, Volume 6: pgs. 197-199, 1997a.

van der Molen, HF; Vink, P.; and Urlings, IJM; A participatory ergonomic approach to the redesign of scaffolders work, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, Tampere, Finland, Volume 1: pgs. 450-452, 1997b.

Wagenheim, M.; Samuelson, Björn; and Wos, H.; ARBAN-A force ergonomic analysis method, Chapter 21 in *The Ergonomics of Working Postures*, International Occupational Ergonomics Symposium, April 15-17, 1985, Zadar, Croatia (Yugoslavia), Eds. Nigel Corlett, John Wilson, and Ilija Manenica, London, Taylor and Francis, pages 241-255, 1986.

Wakula, J.; Wimmel, F.; Linke-Kaiser, G,; Hoffman, G.; and Kaiser, R.: Ergonomic Analysis of load on the back in concrete work, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, 1997, Tampere, Finland, Volume 6: pgs. 191-193, 1997.

Washington State Department of Labor and Industries (WA DL & I), *Work-Related Musculoskeletal Disorders: Washington State Summary 1992-1994*, October, 84 pages, 1996.

Wigmore, D; Moir, S; Bright ideas: construction worker's innovations on the job, Presentation to the American Industrial Hygiene Conference and Exposition, Dallas, TX, May 19, 1997.

Zimmermann, CL; Cook, TM; Rosecrance, JC: Trade-specific trends in self-reported musculoskeletal symptoms and job factor perceptions among unionized construction workers, *Proceedings of the 13th Triennial Congress of the International Ergonomics Association*, June 29–July 4, Tampere, Finland, Volume 6: pgs. 214-216, 1997a.

Zimmermann, CL; Cook, TM; Rosecrance, JC: Work-related musculoskeletal symptoms and injuries among operating engineers: a review and guidelines for improvement, *Applied Occupational and Environmental Hygiene*, 12 (7): 480-484, July 1997b.