Physical Risk Factors and Controls for Musculoskeletal Disorders in Construction Trades

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Abstract: Adoption of the Washington State Ergonomics Rule in 2000 initiated seven different demonstration projects in nine high-risk construction trades. The Ergonomics Rule was repealed in 2003, however valuable cooperative field research was conducted in construction prior to rule dissolution. This paper presents summaries and results of each project with the aim of providing the results to construction professionals and researchers seeking to identify and reduce injury risks and building costs. The projects were organized independently but each with the specific aims of conducting work in conjunction with industry, identifying "hazard zone" risk factors as defined by the rule, and identifying feasible solutions in agreement with company partners to mitigate these risk factors. Musculoskeletal injury risk factors were evaluated by ergonomist field observation and working group analysis. Solutions were developed through field work and consensus agreement with industry and labor representatives. Identified injury risk factors and technically feasible interventions are presented for the following trades: Roofing, residential framing, residential carpet and floor installation, commercial carpentry, commercial laborers, commercial concrete reinforcement, commercial concrete finishing, drywalling, and masonry.

DOI: 10.1061/(ASCE)0733-9364(2006)132:10(1059)

CE Database subject headings: Occupational safety; Safety programs; Injuries; Accidents; Construction industry; Cost control.

Introduction

Construction continues to be one of the highest risk industries for the development of work-related musculoskeletal disorders (WMSDs). Washington State previously initiated projects in multiple industries as part of an ergonomics rule implementation to identify WMSD hazards and feasible low-cost solutions. Twelve high-risk industries, identified by the Standard Industrial Classification (SIC) code, were required to come into compliance first under the rule. These industries were chosen largely based on their prevention index, which is a combination of musculoskeletal injury incidence rate and total number of injuries (Silverstein et al. 2002). Construction was ranked as the highest risk industry for State Fund compensable claims for nontraumatic soft tissue disorders of the upper extremity, neck and back for the period 1990–1998. Five specific construction sectors were ranked in the top ten across all industries and included in the first Ergonomics Rule compliance phase: (1) Residential construction (wood frame building); (2) roofing; (3) masonry; tile setting; and plastering (includes drywall installation); (4) commercial building construction (carpentry and floorwork); and (5) concrete construction. Nine primary trades were identified in these five sectors for project development.

Previous studies have documented the presence of injury risk factors and possible interventions in multiple commercial and residential construction trades (Schneider and Susi 1994; Everett 1997). However, longer studies that involve detailed field assessment of risk factors combined with regular expert focus group agreement on risk factors and solutions are relatively rare. This paper summarizes several independent projects that represent several years of work by field researchers along with industry and labor partners to identify the highest risk activities, risk factors, and practical solutions for mitigation. The studies were not meant to be scientifically rigorous but all employed accepted field assessment methods. The strength of the information presented lies in that each identified activity, risk factor, and solution was identified by experienced ergonomists through extensive field observation, and by consensus agreement with contractors, workers, manufacturers, and material suppliers.

There are several previous studies of risk factors or interventions that involve trades from the presented projects. A study by De Jong et al. (2003) evaluated adoption of interventions and perceptions of workload and work methods in bricklaying. One of the findings was that changes in work methods could have been achieved more easily with more participation by the bricklayers and affected workers. Van der Molen et al. (1998) observed risk factors and outlined a prevention strategy for reducing the physical workload of gypsum bricklayers. Another longer project at a manufacturing plant construction site has yielded risk factor and intervention information for several trades including plumbing and mechanical (Hecker et al. 2001). Very few studies exist that provide detailed risk assessment and intervention development across a trade in a variety of work environments.

Intervention research has been conducted for promising injury reduction solutions in a variety of trades. A study by Berndsen

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Note. Discussion open until March 1, 2007. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on November 23, 2005; approved on March 24, 2006. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 132, No. 10, October 1, 2006. ©ASCE, ISSN 0733-9364/2006/10-1059–1068/$25.00.

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Table 1. Washington Ergonomics Rule Caution Zone and Hazard Zone Risk Factor Levels

Risk factor	Caution zone level	Hazard zone level
Hand over head or elbow over shoulder	>2 h	>4 h
Hand over head/elbow over shoulder >1/min		>4 h
Neck or back bent >30°	>2 h	
Neck bent >45°		>4 h
Back bent >30°		>4 h
Back bent >45°		>2 h
Squatting	>2 h	>4 h
Kneeling	>2 h	>4 h
Highly repetitive motion (hands, arms, neck, back)	>2 h	>6 h
Pinch grip 0.9 kg (2 lb) object or pinch with 17.8 N (4 lb) force, or	>2 h	
Power grip 4.5 kg (10 lb) object or grip with 44.5 N (10 lb) of force		
High hand force with/highly repetitive motion		>3 h
High hand force with/awkward postures		>3 h
High hand force with/awkward postures and repetitive motion		>2 h
Intensive keying	>2 h	>7 h
Intensive keying with/awkward postures		>4 h
Hand or knee impacts >10/h	>2 h	
Using hand or knee as hammer >1/min		>2 h
Moderate hand-arm vibration	>2 h	Refer to Rule Appendix B
High hand-arm vibration	>.5 h	Refer to Rule Appendix B
Lifting >34.1 kg (75 lb), >25 kg (55 lb)>10/day, >4.5 kg (10 lb) >2/min>2 h, or >11.4 kg (25 lb) in awkward posture >25/day	Any of these	Refer to Rule Appendix B

(1990) observed risk factors in bricklayers both with and without mechanized interventions. Mirka et al. (2003) evaluated prototype interventions for residential framing carpenters and documented reductions in spine compression forces. Bronkhorst et al. (1997) evaluated new tools for glaziers to reduce lifting. A study by Cutlip et al. (2000) determined the least stressful method of scaffold construction. A reduction in force requirements using a powered carpet stretcher was found when compared to manual stretching in a study by Village et al. (1993). Landau and Wakula (1997) documented reductions in force requirements in bricklaying, ceiling installation, and tile laying through the use of hand holds, tool supports, ceiling jacks, and height-adjustable work surfaces. These studies and others provided useful information for cooperative projects in the construction sector.

The Washington State Ergonomics Rule (L&I 2000) required employers to evaluate what all of their employees do and determine whether one or more caution zone risk factors (WAC 296-62-05105 "What is a Caution Zone Job") are present on the job more than one day a week and more than one week a year. If at least one of these risk factors was present, then all employees performing this job and their supervisors needed to be given ergonomics awareness training and their jobs analyzed to determine whether hazard zone level risk factors (WAC 296-62-05174, Appendix B) were present. Performing hazard zone analysis required that a trained person or people perform more detailed assessments of the caution zone jobs using formal evaluation methods to determine the level of risk. If a risk factor is in the hazard zone for a particular job, then the exposure had to be eliminated or reduced below the hazard level or to the degree feasible.

Table 1 details risk factor levels for identification of a caution zone job, and hazard zone risk factors. Lifting hazard analysis required calculations with inputs that included the weight, frequency, duration, and position of the item lifted. The maximum acceptable weight under the rule was 40.9 kg (90 lb) if lifted from knee to waist height, and 31.8 kg (70 lb) if lifted from foot level. Hazard analysis of hand-arm vibration was performed by checking declared tool vibration levels and time of exposure against a graph in the Ergonomics Rule, Appendix B.

The Washington State Department of Labor and Industries completed public Ergonomics Demonstration Projects in each of the high-risk construction trades. The goals of these projects were arrived at independently with companies and industry groups partnering to assess the impact of the Ergonomics Rule. Each project systematically identified physical risk factor levels and feasible solutions to reduce hazards, despite differences in evaluation methods and solution generation based on consensus agreement with partners. Each group concluded that most field jobs in construction would have at least one "caution zone" risk factor, so evaluations focused on analysis and solutions development for risk factors that likely exceeded the hazard zone levels. This paper summarizes the project methods, hazard zone risk factors identified, and solutions agreed upon with industry partners by construction trade.

Construction is difficult to study due to scheduling demands, variation in work conditions and methods, and the nonfixed nature of the work. Injury risk factors were identified on worksites and low-cost, real-world solutions were developed in conjunction with workers and contractors. This information is valuable to engineers, contractors, and researchers for injury and cost reduction in one of the highest risk industry sectors.

Methods

The process for task identification, risk factor evaluation, and solution development is presented for each project. Most of the project work involved working groups with the goal of achieving consensus between industry, labor, and government representatives on possible risk factors and acceptable mitigating solutions. However in each case, a trained ergonomist performed standard work sampling or time-motion study of construction tasks to

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make quantifiable determinations of the risk levels. Possible lifting hazards were all evaluated using the lifting analysis procedure detailed in Appendix B of the Washington State Ergonomics Rule. Tasks are identified as having "potential" hazard zone risk factors because variability in types of construction, amount of work, and method make it difficult to make absolute determinations that would apply to every building site. The projects are presented by trade. A total of nine trades were evaluated through seven demonstration projects: Roofing, residential framing, residential carpet and floor installation, commercial carpentry, commercial laborers, commercial concrete reinforcement, commercial concrete finishing, drywalling, and masonry.

Project Findings

Roofing

Roofing Project Methods

The Ergonomics Demonstration Project in the roofing industry was initiated with the Washington Roofing Contractors Association (RCA) in January 2000. This ergonomics committee consisted of members of the RCA, labor and industries, a business representative, and a labor representative. Bimonthly meetings were conducted with group members for one year. Initial risk factor identification began with a list of tasks and rated risk factors from a construction ergonomics document published by the Univ. of Michigan (Everett 1997). Agreement was achieved on a list of primary residential and commercial roofing tasks. Activities with risk factors ranked as a three (on a three-point scale) from the Everett (1997) report were given priority. These tasks were categorized by the group as possible hazard zone tasks. Approximately six months of field work was initiated by an ergonomist visiting different types of roofing sites to learn about the different types of roofing for identification of primary tasks and hazards. Video and still pictures were taken of all possible hazard zone tasks, and time-motion analysis was conducted on specific tasks to estimate risk factor levels. Frame-by-frame analysis of repetition and postures was conducted of at least three job cycles of tasks from at least two different job sites to make a dichotomous risk level determination.

A summary of potential hazard zone risk factors and possible solutions by task were developed from the field observations. The committee brainstormed solutions for each task with a hazard zone risk factor at regular group meetings. Ideas for reducing hazard zone risk factors were also solicited from contractors, employees on sites, equipment manufacturers, and ergonomists. Additionally, a questionnaire was sent to all members of the RCA asking for input on solutions for the identified high-risk activities. Many technically feasible, low-cost solutions were identified through this process. In most cases, several acceptable solutions were identified which could reduce the risk factor level below the hazard zone. This information was summarized, discussed, and agreed upon in principle by the committee. The final consensus on potential risk factors and solutions was then summarized by type of roofing activity.

Roofing Project Results

Agreement on hazard zone risk factors and feasible solutions was reached by consensus among the roofing committee members. Heavy, frequent, and awkward lifting was identified as a potential hazard zone risk factor for all roofing activities with the exception of roof insulation installation. Back bending was identified for installation activities, and high hand force with repetition was observed during roof removal and roofing installation. Kneeling or squatting and moderate hand-arm vibration were identified for new roofing installation. A summary of risk factors and controls by major roofing task are presented in Table 2.

Mechanical equipment controls and tool solutions were preferred when possible. However, many jobs may preclude the use of equipment due to factors such as access, structural support, and safety considerations. Training on methods that rely on worker behavior was identified as a secondary control where engineering or administrative controls were not feasible. Training on lifting techniques includes teaching workers to lift felt rolls and shingle bundles over the knee to raise the effective lifting height, and limiting repetitively lifted loads such as tear-off material. Workers would also be trained to use an arm for support when bending and to slide or roll materials into place or onto carts instead of lifting.

Residential Construction

Project Methods

The residential construction evaluation project was done as a Univ. of Washington research and consultation project. Partnerships were formed with several residential construction companies to evaluate common tasks and identify possible injury risk factors and controls. Exposure assessment was performed by ergonomist observation in the field for house framers, carpet installers, and hardwood floor installers. A total of six framing crews, one carpet-laying crew, and one hardwood floor installer were observed as part of the project. The participating contractors generally built different styles of two-story wood frame house construction. Possible solutions to mitigate hazard zone risk factors based on the Ergonomics Rule were developed by informal discussions with workers and contractors as well as through research into tool options and alternative construction methods.

Evaluation of risk factors was conducted by using a work sampling method called PATH (posture, activity, tools, and handling) developed by Buchholz et al. (1996). Using this method, postures and activities were recorded once a minute during observations of the different crews. Eleven observation sessions of 2–3 h were conducted at random times. More than 3,300 observations of 23 residential framers on three different sites were taken to arrive at estimates of exposure. One crew of three carpet installers was observed for a total of 480 observations. Exposure for one hardwood floor installer was assessed by 254 observations.

Residential Construction Results

The findings of this project documented two possible hazard zone risk factors to which residential framers may be exposed during regular work. Three possible hazard zone risk factors were found in carpet installation and one hazard zone risk factor in hardwood floor installation. Residential framers were exposed to back bending greater than 45° for more than 2 h during wall building and floor deck installation. However, floor deck installation was not observed being performed more than once per week by the crews, and thus did not qualify as a hazard zone task under the Ergonomics Rule. Framers were exposed to heavy lifting greater than 40.9 kg (90 lb) when lifting header beams, trusses, and wall sections. Lifting of heavy material may also present an exposure above hazard zone levels if workers attempt to lift too much material at a time and in an awkward manner.

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Table 2. Physical Risk Factors and Identified Controls for Roofing Tasks

Task	Potential hazard zone risk factors	Identified controls
Old roof removal	Heavy, frequent, awkward lifting	Use mechanical lifting, cutting and removal equipment when possible
	High hand force with awkward posture and repetitive motion	Use wheelbarrows/carts to move old roofing when possible
		Use shovels to lift small items into wheelbarrow or cart
		Rotate workers to other tasks if possible
		Use two workers to lift weights over 40.9 kg (90 lb)
		Train workers on proper lifting and shoveling techniques/weights
Installing new roofing	Heavy, frequent, awkward lifting	Use mechanical devices to apply roofing when possible
	High hand force with repetitive motion	Use mechanical devices to spread gravel when possible
	Back bending >45°	Use mechanical seam welding equipment when possible
	Kneeling and squatting	Use powered mechanical caulk equipment when possible
	Moderate hand-arm vibration	Use long-handled fastening tools when possible
		Use low-vibration tools or tool handle wrap
		Rotate workers to other tasks if possible
		Provide workers with knee pads when kneeling
		Arrange material to minimize twisting and bending
		Allow workers to choose between various mop sizes
		Train workers on proper lifting and bending techniques
		Train workers to roll or slide materials instead of lifting
		Train workers to slide shingles into place instead of lifting
		Train workers to change body positions (i.e., kneel, sit, stoop)
Loading roofing materials	Heavy, frequent, awkward lifting	Use mechanical loading equipment when possible
		Use wheelbarrows/carts to move material when possible
		Arrange material to minimize twisting and bending
		Rotate workers doing lifting when possible
		Use two workers to lift weights over 40.9 kg (90 lb)
		Train workers to roll or slide materials instead of lifting
		Train workers on proper lifting techniques
Moving materials on the roof	Heavy, frequent, awkward lifting	Use mechanical lifting equipment when possible
		Use wheelbarrows/carts to move material when possible
		Arrange material to minimize twisting and bending
		Rotate workers doing lifting when possible
		Use two workers to lift weights over 40.9 kg (90 lb)
		Train workers to roll or slide materials instead of lifting
		Train workers on proper lifting techniques
Loading asphalt kettle	Heavy, frequent, awkward lifting	Break-up blocks over 40.9 kg (90 lb) into three or more pieces
		Roll asphalt kegs rather than lifting from pallet
		Purchase smaller asphalt blocks to reduce weight
		Use an asphalt tanker truck instead of a kettle
		Use carts/wheelbarrows to move block if necessary
		Train workers on proper lifting techniques
Installing roof insulation	Back bending >30° and >45°	Use long-handled fastening tools if possible
		Rotate workers to other tasks if possible
		Train workers to change body positions (i.e., kneel, sit, stoop)

Residential Framing Results

Solution options of very low cost were found that would address each of these risk factors for residential framers. Use of fastener tools with handle extensions costing $100 or less was identified along with job rotation as possible easy solutions for reducing back bending during floor deck installation. Wall building likely presents a longer exposure and fewer options for risk factor reduction were identified. Raising the working height by using sawhorses and job rotation are possible options, though other construction methods should be investigated. Heavy lifting can be reduced relatively easily by using boom trucks, powered lifts, hand-crank lifts, jacks, pneumatic lifters, and team lifting. The hazard zone risk factors and possible solutions identified for residential framing are summarized in Table 3.

Floor and Carpet Installation Results

Carpet installation had three potential hazard zone risk factors. Kneeling more than 4 h could be observed while installing tack strips and carpet padding if done all day, though not normal for the observed installation crew. Knee impact more than once per

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Table 3. Physical Risk Factors and Identified Controls for Residential Framing Tasks

Task	Potential hazard zone risk factors	Identified controls
Floor deck installation	Back bent > 45° more than 2 h	Use of a screw gun or nail gun and glue gun with handle extension Rotate to different tasks during the day if possible
Wall building	Back bent > 45° more than 2 h	Use sawhorses for cutting material Training to alternate body postures and activities Rotate to different tasks during the day if possible
Lifting/placing header beams	Heavy lifting	Use a boom truck to lift and position beam Deliver beam near final location and use a crank/power lift Deliver beam onto sawhorses, lift with 3–4 workers at all times
Lifting trusses and sheeted end gables	Heavy lifting	Use a boom truck to lift and position truss Use a powered lift or jack past shoulders, then walk up
Lifting wall sections	Heavy lifting	Use wall jacks or pneumatic lifter Use a boom truck for wall sections > 3 m (10 ft) tall Team lift interior (nonsheeted) walls
Lifting material	Heavy lifting	Limit lifting of material [one plywood sheet, two 3 m (10 ft) 4 × 4 s…] Train proper lifting (walk-up loads, keep close to body, avoid twisting)

minute for more than 2 h/day was observed while installing carpet using a knee kicker. Heavy lifting greater than 40.9 kg (90 lb) is possible when moving rolls of carpet. Back bending greater than 30° for more than 4 h would also be present if tack strip installation was performed regularly all day, though this is not likely the case. Workers should be provided with appropriate training to alternate body postures, and rotate tasks to reduce exposure to kneeling risks. Knee pads should also be provided, though this does not reduce exposure to kneeling. Knee impact may be easily reduced by using a carpet stretcher and only employing a kicker when necessary. Heavy lifting of the carpet rolls from the vehicle can be eliminated by attaching the roll to a fixed point using a strap and then moving the vehicle away. The carpet can then be rolled to a location where it can be cut into room-size pieces for installation, such as the driveway or garage. Other heavy items such as tools and equipment can be moved either with a handtruck or by team lifting.

Hardwood floor installation had back bending greater than 30° more than 4 h and bending greater than 45° more than 4 h as a hazard zone risk factor. As a single person frequently does this activity, job rotation options may often be limited. Workers can be trained to alternate body postures, plan work to break up back bending, and take frequent minibreaks to reduce exposure to this risk factor.

Commercial Building Construction: Carpentry, Laborers, Concrete Reinforcement, and Concrete Finishing

Carpenters and Laborers Project Methods

The project in commercial carpentry and labor was initiated with workers at a building site of two five-story office buildings. Workers were trained on ergonomic risk factors and the Washington State Ergonomics Rule during toolbox meetings. Selection of possible hazard zone work activities was conducted on a weekly basis through review of up-coming tasks in the project cycle. These activities were identified by discussion during the weekly safety meetings, conducted with all site workers each Monday morning before the start of work. Formal exposure assessment was conducted for carpenters and laborers in identified activities by a trained ergonomist. Potentially hazardous tasks for other trades discussed in the meetings were informally investigated for hazard zone risk factors and solutions on a case by case basis.

Exposure assessment was performed through work sampling of tasks by taking a "mental snapshot" of an activity every 60 s and recording observed risk factors. Observed risk factors were marked on a sampling data sheet designed to measure hazard zone risk factors. A total of 703 observations of carpentry were taken including the following tasks: Building gang forms, installing gang forms, building vertical and footing forms in place, building column and beam forms, installing deck form sheeting, and installing deck form supports. A sample of 177 observations were taken of laborers for five activities: form stripping, soil compacting, concrete pouring/spraying, and raking/digging.

Solutions were developed through informal discussion with workers, observation on-site, and research into possible product or engineering controls. Confirmed potential hazards and possible solutions were then presented to workers at the next weekly safety meeting for discussion. Feasible solutions were chosen and workers were asked to perform any identified work practices for the remainder of the project to mitigate confirmed hazard zone risk factors.

Carpentry and Laborers Project Results

Back bending was observed as a potential hazard zone risk factor when constructing deck forms and other floor level work during the whole day. No hazard zone risk factors were observed for workers constructing supports; however, this was done at this site using a newer aluminum deck system. Higher levels of risk factors may be present in older systems using wood beams. Back bending was above the hazard zone level for deck sheeting work; however, limited modifications could bring it down from the observed 32% of the 8 h day to the goal of 25% or below.

Lifting material and equipment was an infrequently observed hazard zone risk factor. Lifting material over 40.9 kg (90 lb) or lifting heavy material such as HDO plywood incorrectly from the

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Table 4. Physical Risk Factors and Identified Controls for Commercial Carpentry Tasks

Task	Potential hazard zone risk factors	Identified controls
Moving equipment	Heavy, frequent, awkward lifting	Use mechanical equipment such as cranes or forklifts Get help from another worker if equipment is not available
Moving material	Heavy, frequent, awkward lifting	Use mechanical equipment or get help if >40.9 kg (90 lb) Limit loads of multiple pieces of material to 31.8 kg (70 lb) maximum Lift up to 40.9 kg (90 lb) occasionally using the walk-up technique Place load close to work, use pallet jacks/slide if frequent
Install deck form sheeting	Back bending >45° more than 2 h	Use a nail gun with handle extension Rotate between deck support and deck sheet installation Perform cuts on saw horses or plywood stack
Gang form construction	Back bending >45° more than 2 h	Use a screw-gun with handle extension Perform cuts on saw horses or plywood stack

ground was observed in some cases. Carpenters usually did not lift weights more than 40.9 kg (90 lb) or 31.8 kg (70 lb) from the ground when moving multiple pieces of material; however, workers may sometimes lift more material when in a hurry or to reduce the number of trips. In almost all cases, heavy lifting is easily mitigated either by using mechanical equipment, by getting help from another worker, or by positioning and lifting the material correctly. Table 4 summarizes the hazard zone risk factors and solutions by task for carpenters.

Some workers were observed using a walk-up lifting technique. This method of lifting is performed by lifting up one end of material such as lumber, and then walking toward the middle of the length of material until it can be balanced on the shoulder. This method of lifting makes it possible to occasionally lift materials up to 40.9 kg (90 lb) under the Ergonomics Rule. Common materials were weighed and approximate maximum numbers and lengths of lumber were derived for lifting guidelines, if done using the walk-up technique or from a raised height. Examples of maximum load for commonly lifted materials for carpenters and laborers presented on the worksite were: Two 3.05 m (10 ft) 4×4's, three 3.05 m (10 ft) 2×6's, and one 1.2 m×2.4 m (4 ft×8 ft) sheet of 1.9 cm (3/4 in.) plywood.

Typical tasks observed for laborers site included: Soil preparation and compaction, pouring concrete, and spraying concrete slabs. Hazard zone risk factors were observed during concrete-related activities for laborers at this site. Soil compaction was performed using self-supporting, hand-guided soil compactors, which was not covered for hand-arm vibration under the Ergonomics Rule. However, if hand-held soil compactors were used, then it would have been necessary to limit hand-arm vibration exposure to levels below the hazard zone described in Appendix B of the Washington State Ergonomics Rule. Exposure can often be limited by task rotation, choosing a tool with less vibration, or by provision of antivibration gloves if no other alternatives are feasible.

High hand force with awkward postures may be possible if shoveling or trenching were performed all day on multiple days, however this was not observed at the demonstration project sites. Another possible hazard zone risk factor, though also not observed in this case, could be using a chipping hammer for extended periods on multiple days. As with a nonsupporting soil compactor, the amount of time a worker can use the tool depends on the declared level of hand-arm vibration from that specific tool. High vibration tools such as chipping hammers may be above the hazard zone level if workers are using them regularly for more than half the day. However, each tool used regularly above the caution zone levels of 30 min total duration for high vibration tools or two hours for moderate vibration tools, should be evaluated individually with respect to hazard zone limits as used.

Concrete Reinforcement and Finishing Project Methods

A total of 15 site visits were conducted over a 3 month period to a four-story commercial office building site. The same observational work sampling technique used for carpenters and laborers was employed to quantify risk factors. A total of 322 samples were recorded for rebar work and 272 samples were taken for concrete finishing over the 15 days. Workers were observed randomly to provide a general picture of as many tasks as possible.

Rebar reinforcement workers observed and interviewed during the project were involved with all aspects of rebar installation. The primary tasks included moving rebar rods to the installation point, placing rebar in place for footings, columns/beams, walls and slabs, and tying rebar for footings columns/beams, walls and slabs. Concrete finishers on this project normally worked in a team of approximately eight people and were on site for a day at a time only for slab pours. The primary pour team usually consisted of one hose person, two people holding/operating the vibrating machine, two people muck raking the concrete into place, two people rodding (screeding) the concrete flat, and one person using a bull float. After the concrete had set up, two people were rotated to powered troweling, brushing the finish, and manual troweling the slab edges while kneeling on skids.

Concrete Reinforcement and Finishing Project Results

Rebar work had three risk factors slightly over the hazard zone limits: High right-hand force with awkward posture and repetition more than 2 h/day, back bent>45° more than 2 h/day, and lifting>31.8 kg (70 lb) from the ground. Concrete finishing had no hazard zone risk factors as an overall average across tasks, however, workers performing the rodding (screeding) task had one hazard zone risk factor if this were done for 8 h: Back bent>45° more than 2 h/day.

High hand force with repetition and back bending during rebar tying may both be mitigated by use of a powered rebar tier. A tier commercially available in the United States currently can tie rebar at a rate of approximately 1 tie/s and can use standard gauge wire on rebar up to No. 10 bar. A handle extension is available so the work can be done from a standing position. A model of this tier was used on site and found to be a feasible solution for mitigating risk factors. The participating contractor had concerns of durabil-

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Table 5. Physical Risk Factors and Identified Controls for Drywalling Task

Task	Potential hazard zone risk factors	Identified controls
Stacking moving drywall	Heavy, frequent, awkward lifting (one-person lift)	Use knuckle booms and equipment to place stock
		Place pallets on carts, store stacks near area of installation
		Move one sheet at a time using proper teamwork
		Follow one-person lifting limits
		Slide boards onto panel lift
Hanging drywall	Heavy frequent, awkward lifting (one-person lift)	Use two people to lift drywall > 1.3 cm (1/2 in.) thick × 2.7 m (9 ft) long
	High hand force with awkward posture and repetitive motion	Use pneumatic or manual panel lift for overhead work
		Order drywall in 2.7 m (9 ft) lengths instead of 3.7 m (12 ft)
		Rotate to other tasks if screwing-down all day
Taping mudding and sanding	High hand force with awkward posture and repetitive motion	Rotate jobs or tasks regularly (i.e. sand, trowel, mud, …)
	Hands over head more then 4 h	Consider use of spring powered box tool for mudding
		Use a holder to power grip sandpaper/block versus pinch grip

ity and cost with the model of the tool used. However, even use of the tool for part of the day could reduce hand force with repetition and back bending below the hazard zone level.

Rebar workers were observed once lifting greater than 31.8 kg (70 lb) from the ground. This lifting hazard occurred while lifting a bundle of rods and carrying them to the point of application. Most workers naturally limit themselves to lifts that would not be deemed hazardous. Longer rods normally require two workers for lifting and placement due to the amount of bending. Larger bundles of rods and preconstructed sections are often moved by crane. However, occasionally workers may lift one or two too many rods when moving several from the stock to the placement site. This hazard may be controlled through administrative control by greater awareness and enforcement of lifting by foremen. In other cases, planning may allow the use of equipment for moving smaller bundles to different work locations on the site. More rods could also be lifted from the ground under the Ergonomics Rule if the maximum weight is increased to 40.9 kg (90 lb) by use of the walk-up technique, effectively raising the lifting height for the full load.

The concrete finishers typically rotate tasks regularly, in large part because the rodding task in particular is very strenuous on the back. There were no hazard zone tasks for concrete finishing overall, however, rodding would be in the hazard zone for back bending $>45°$ more than 2 h/day if it was performed all day. This is not normally the case for the workers observed and interviewed on this project. However, there may be companies or sites where regular rotation is not practiced. It should be a general practice, where possible, to rotate workers between tasks and assure that no worker spends more than half the day either rodding or finish hand troweling. Powered screeds were also used for rodding on-site for larger pours, which is a feasible intervention to reduce back bending. Kneeling may exceed 4 h for finish troweling in some instances, however, this was not observed. Back bending was not recorded as a risk factor for finish troweling because the back was supported at most times with one arm resting on a trowel.

Drywalling and Masonry Project Methods

Masonry and drywalling were initiated as separate demonstration projects, however both used the same approach to exposure assessment and solution identification. Working groups were formed consisting of contractors, business representatives, labor representatives, materials suppliers, manufacturers, and labor and industries representatives. These groups met regularly for a period of over 1 year. These groups used their knowledge of the industry and jobs to identify tasks and risk factors that had the potential to reach hazard zone levels. An ergonomist visited multiple sites to videotape and document these tasks for further analysis. Time-motion study from video of at least 10 job cycles at three different work sites for each activity of interest was used to quantify risk factor levels and determine whether hazard zone risk levels were achieved. The working groups then identified controls that were currently used by some contractors, or other technically feasible solutions.

Drywalling and Masonry Project Results

Drywallers were observed lifting panels weighing more than 40.9 kg (90 lb). This hazard zone activity can be mitigated using a combination of approaches. Limiting the size of wallboard one person is allowed to lift will assure compliance with a 40.9 kg (90 lb) limit. Use of equipment such as knuckle booms and forklifts for stocking, and panel lifts for hanging can reduce the amount of lifting while stocking and installing the boards. Regular job rotation was recommended for hanging and finishing drywall to reduce the exposure to high hand force with repetitive motion that could occur if screwing down panels, sanding or taping/mudding all day. Using tools such as a spring-loaded box tool for mudding or a power-grip handhold for sanding may also reduce hand force requirements. Two people or mechanical aid is needed to lift larger drywall panels unless they can be tilted and slid into place on the wall or lift. Table 5 presents identified potential hazard zone risk factors and controls for drywalling.

The drywalling working group initially focused on the size and weight of drywall due to required action based on previous legislation. Reducing the width of drywall from 1.2 m (4 ft) to 0.9 m (3 ft) was not deemed feasible in the short term but lengths of drywall meeting hazard zone criteria were derived by type of board and application. Maximum lengths for one-worker lifts of different wallboard types were agreed upon by the working group, based on a 40.9 kg (90 lb) lifting limit. A 3.7 m (12 ft) length limit was agreed upon for 1.25 cm (1/2 in.) regular drywall panels, a 3.0 m (10 ft) length limit for other 1.25 cm (1/2 in.) panels and regular 1.6 cm (5/8 in.) regular panels. A 2.4 m (8 ft) limit was determined for exterior panels.

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Table 6. Physical Risk Factors and Identified Controls for Masonry Hodcarrier Tasks (Hodcarriers)

Task	Potential hazard zone risk factors	Identified controls
Scaffolding construction	Heavy, frequent, awkward lifting	Use forklifts
		Lift/carry one frame or plank at a time (manually)
		Use walk-up technique for lifting planks
		Use additional workers for lifting heavier planks
Mixing/stocking mortar	Heavy, frequent, awkward lifting	Use a silo for large projects
	High hand force more than 4 h	Use small bags (23 kg maximum) or cut bags in half
		Place bags off ground and lift close to body
		Distribute mortar by forklift/tub
		Limit wheel barrow lifting load to 40.9 kg maximum
		Rotate to other tasks when possible
Stocking block	Heavy, frequent, awkward lifting	Load pallets with block grip flange on top
	High hand force more than 4 h	Use hand truck distribution of block (with banding)
		Use block buggies
		Rotate to other tasks when possible.
Using grout hose	High hand force more than 4 h	Use other procedures such as a grout hog
		Rotate worker positions on hose
		Rotate to other tasks such as stocking
Consolidation	High hand force more than 4 h	Use low-vibration vibrators
	High hand arm vibration	Rotate to other tasks when possible

Masonry tasks were divided into hodcarrier tasks and installation tasks. Table 6 presents a summary of the working group findings for hodcarrier activities. Heavy, frequent lifting, and high hand force were the primary risk factors of concern. Mechanical, work organization, and work method controls are all available to reduce the identified risk factors below the hazard zone level.

Physical exposures during masonry installation varied depending on the material and location. Work organization techniques and administrative controls may be employed to control most risk factors, particularly on larger jobs with a group of masons. Mechanical controls and lifting assists for heavier materials were identified as an efficient way to reduce lifting hazards. A summary of potential hazard zone risk factors and control findings is presented in Table 7.

Discussion

The work conducted through these evaluations in construction has demonstrated that significant injury risk factors do exist above the defined hazard zone levels, and that feasible solutions generally do exist for reducing worker exposures. Despite sometimes heated debates, each working group was able to achieve consensus agreement on potential risk factors by task and acceptable solutions. Solution development focused first on lower-cost solutions that could be easily implemented. However all possible interventions were considered and preference was given to engineering and administrative control strategies over those relying on employee behavior. Solutions listed in the results had to be either demonstrated in practice or deemed easily implemented by the participating contractors and labor and business representatives. The results indicate that feasible solutions meeting these criteria are available to reduce the level of identified risk factors.

Although each project was not designed to be scientifically rigorous, the methods used in all commercial construction projects did base risk factor level determination by using both accepted field measurement techniques, and by obtaining construction expert group consensus on the content of tasks and applicability of controls. The mitigating interventions identified were significant, in that a probable assumption by many in the working groups was that these solutions would essentially become part of a de facto regulation. Because of this, achieving agreement on the listed interventions meant that contractors and workers in each of these trades believed that the ideas were feasible to implement in productive businesses.

The risk factors in the studied trades were presented dichotomously, classifying exposure as either above or below hazard zone levels. The exposures were quantified through field observation in the process of achieving this determination, but were presented in this manner to promote generalizability to different construction sites, and for ease of discussion among working group members in achieving agreement on Washington Ergonomics Rule requirements. It should be recognized that the risk factor levels in the Ergonomics Rule were set through a regulatory process, and in some cases such as with lifting, occupational health experts might argue that these levels do not reduce risk to an acceptable level. While the identified interventions can reduce the physical exposure to workers, there will still be a resulting risk of injury.

More limited sampling was performed for laborers, concrete reinforcement, and concrete finishing due to project constraints. The small number of observations makes it difficult to generalize the results due to possible differences in work methods and changes in the process over time. However, it was determined that enough samples were taken in each project to make the appropriate dichotomous hazard zone level judgments for each risk factor in the observed activities. Error due to work sampling from a binomial distribution was estimated according to Neibel (1976) and ranged from 1% for residential framing up to 10% for laborer activities.

The field observations included multiple sites and employers to obtain a representative sample of work methods for identified tasks in each trade or subspecialty that could be generalized. Additionally, the task analysis and work methods were discussed

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Table 7. Physical Risk Factors and Identified Controls for Masonry Installation Tasks

Task	Potential hazard zone risk factors	Identified controls
Saw cutting	Back bent > 30° more than 4 h Back bent > 45° more than 2 h Neck bent > 45° more than 4 h	Adjust saw table height Stock blocks up off the ground Rotate to other tasks when possible
Repetitive laying (all day)	High hand force with bent wrist > 3 h Highly repetitive motion	Place block with two hands above waist height Butter block on leg, mud board, or block stack Rotate between laying, striking, cleaning, or wiping Do not limit tasks to only buttering or picking
Stocking tile/thinset	Heavy, frequent, awkward lifting	Distribute pallet loads with forklift, boxes/bags with handtruck Store boxes/bags at a raised height (on pallets) Lift/carry on box/bag at a time Distribute mixed thinset in partially filled or smaller buckets Use handtruck to distribute mixed thinset in larger buckets
Grouting	Highly repetitive motion with high hand force	Rotate with tile setter, or to tasks such as scraping and stocking
Installing floor tile	Kneeling more than 4 h	Rotate keeling tasks with the apprentice Alternate between kneeling, squatting, sitting and stooping Rotate to non-floor tile installation when possible
Installing wall tile	Hands above head/elbows above shoulder Kneeling more than 4 h Buck bent > 30° more than 4 h Back bent > 45° more than 2 h Repeated impact (hand) more than 2 h Highly repetitive motion with high hand force	Rotate to tile installation at other levels Sit on bucket, stool, or rolling cart for low wall work Alternate between kneeling, squatting, sitting, and stooping Use a wooden board and hammer or rubber mallet to set Press tiles instead of impacting with hand Rotate out of highly repetitive small tile application
Installing ceiling tile	Hands above head/elbows above shoulder Highly repetitive motion with high hand force	Rotate to tile installation at other levels Rotate out of highly repetitive small tile application
Installing pavers	Kneeling more than 4 h Highly repetitive motion with high force Heavy frequent, awkward lifting	Alternate between kneeling, squatting, sitting, and stooping Rotate to non-installation tasks such as finishing Use mechanical lifter/positioner (places multiple pavers at once)

with working groups and contractors to verify completeness. The observations, however, do only apply to the work and methods observed. Construction work can be variable depending on site conditions, building type, differences in systems, variation in work methods and other factors. These differences could either reduce or increase workers exposure to physical risk factors. Site-specific differences also may influence the efficacy of some mitigating solutions or aid in determining intervention preference.

Conclusions

Construction is still one of the highest-risk industries for work-related musculoskeletal disorders. It is hoped that this work will aid in the process of intervention dissemination and implementation in high-risk trades. This study work has shown that field assessment can be done readily and low-cost solutions are available. The results give information necessary to guide intervention activities in these high-risk construction trades. Specific hazards and solution applications may vary depending on the site, type of construction, systems employed, and contractor. However, the results from this work may be applicable across different contractors and sites. In many instances, interventions identified in these projects were ideas already in practice with other contractors. Wider and regular dissemination of these practical solutions could help reduce the risk of injury to many more workers in the different trades.

Acknowledgments

The writers would like to thank Maria Kelley, Jeffry Leons, and the participating contractors, labor representatives, and manufacturers for their help in each of these projects.

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