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Identification of ergonomics interventions used to reduce musculoskeletal loading for building installation tasks

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Abstract

Skilled workers in the mechanical and electrical installation (M/EI) building and construction trades experience high rates of disabling work-related musculoskeletal disorders (WMSDs). The M/EI trades involve installing piping; heating, ventilation and air conditioning (HVAC), and electrical systems in residential, commercial, and industrial buildings. In the absence of an ergonomics standard in the United States, some building and construction contractors, including M/EI sector contractors, have implemented various ergonomics interventions on their worksites on a voluntary basis. However, no data were available to determine the type of voluntary control measures being implemented, the task-specific hazards for which control measures needed to be developed or refined, and perceived barriers to improving hazard control. As part of a larger effort to obtain this data, the National Institute for Occupational Safety and Health (NIOSH) organized a stakeholder meeting to gather information regarding ergonomics interventions or 'best practices' by M/EI contractors and tradespeople. The attendees included 39 industry representatives, 17 construction ergonomics researchers from government and academia, and four ergonomics consultants with experience in the construction industry. Participants spent more than 50% of time meeting in small trade-specific breakout sessions. According to the participants, tasks common to the three trades included (1) drill holes and shoot fasteners; (2) place and install systems, and (3) lift and carry materials and equipment. Engineering interventions described in the stakeholder meeting included tools, equipment, and engineered building materials; administrative controls largely consisted of training and education programs and modifications of work and management practice. Most participants believed that there were significant limits to the impact individual contractors and tradespeople could have in leading ergonomics improvement in the building and construction industry.
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1. Background

Mechanical and electrical system installation workers account for nearly 15% of 9.3 million building and construction workers in the United States in 2000 (CPWR, 2002). Mechanical installation workers install and service piping and heating, ventilation, and air conditioning (HVAC) systems. Piping system workers, which include plumbers, pipe fitters, and sprinkler fitters, install and service the piping systems in commercial, industrial, and residential structures. HVAC system workers, which include sheet metal duct installers and HVAC system mechanics, install and service the air handling systems and the equipment that conditions the air in commercial, industrial, and residential structures. Electricians install electrical systems in commercial, industrial, and residential structures, which include conduit and wiring, fixtures, controllers, and switches.

Although the data are limited, WMSDs are a significant problem for the electrical, pipe, and HVAC systems installation trades. Workers in the plumbing

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and HVAC sector experienced serious overexertion injuries at rates exceeding the national average for all industries and all construction workers; electrician's rates were often higher than the all industry average (Table 1) (BLS, 2004). Between 1992 and 1998, 26% of all mechanical installation workers injuries and illnesses resulting in days away from work that were due to overexertion or repetitive motion (Fredericks et al., 2002). Studies have reported WMSDs among the electrical (English et al., 1989; Hunting et al., 1994), pipe (Hildebrandt, 1995; Ritz and Brunnholzl, 1988), and sheet metal (Welch et al., 1995) trades, and for similar work (Petersen et al., 1981; Herberts et al., 1984; Torner et al., 1991; Sporrong et al., 1999). Rosecrance et al. (2002) reported high rates of carpal tunnel syndrome (CTS) among apprentices working in the pipe, electrical, and sheet metal trades.

When developing and implementing ergonomics interventions in the building and construction industry, an array of technical, organizational and environmental challenges not present in other industries must be considered (Schneider and Susi, 1994). Interventions, however, have been developed for specific work tasks, as well as new construction projects (Hsiao and Stanevich, 1997). Researchers have evaluated interventions for mechanical and electrical installation tasks, including fitting drain pipes (Sillanpaa et al., 1999), overhead use of rotary hammer drills and powder actuated fasteners (Andersson, 1990; Wos et al., 1992), driving screws (Cederqvist et al., 1990; Ortengren et al., 1991), and construction and maintenance installation tasks (de Jong and Vink, 2002). The reports indicated that the interventions reduced exposure to WMSD risk factors. Hecker et al. (2000) described the implementation of training and task interventions implemented during construction of a large semiconductor manufacturing plant in the United States. Other reported intervention activities include a joint labor-management sponsored ergonomics training and education program for the HVAC system installers (SMOHIT, 1999) and the Ohio Bureau of Workers Compensation (BWC) program that provides cash grants to contractors, including M/EI contractors, to purchase ergonomics interventions (OHBWC, 2004).

No data, however, were available in the United States to determine the type of voluntary control measures being implemented, the task-specific hazards for which control measures needed to be developed or refined, and perceived barriers to improving hazard control. After consulting with industry stakeholders, the National Institute for Occupational Safety and Health (NIOSH) decided to organize a stakeholder meeting to gather this information from M/EI contractors and tradespeople. NIOSH researchers believed that recommended 'best practices' generated by M/EI contractors and tradespeople would have greater feasibility and potential for acceptance and use. Sixty researchers, contractors and tradespeople representing the piping/plumbing, heating and air conditioning, and electrical sectors of the US construction industry attended a stakeholder meeting titled "*Exploring Ergonomic Interventions in the Mechanical & Electrical Construction Trades*" in San Jose, CA, in February, 2002. Although experience varied, most contractors and trades people attending the stakeholder meeting had previous experience implementing or using ergonomics interventions. Meeting in small groups, M/EI contractors and tradespeople were asked to (1) describe task-specific WMSD risks; (2) describe the ergonomics interventions available and used by some in the M/EI trades; and (3) identify interventions requiring further evaluation and/or problematic tasks lacking an effective intervention. This paper reports the answers provided by participating M/EI contractors and tradespeople (i.e., stakeholders) for similar installation tasks.

Table 1
Rates[a] of injuries and illnesses due to overexertion for all industries, all construction, and M/EI workers

Year	All workers	All construction	Plumbing & HVAC	Electrical
2002	49.7	62.1	73.6	46.0
2001	45.0	63.2	77.8	48.5
2000	49.5	70.6	76.3	71.1
1999	50.8	68.7	85.0	56.4
1998	53.8	66.3	68.9	50.4
1997	58.8	85.2	103.1	63.6

[a]Rates per 10,000 workers for injuries and illnesses resulting in one or more days away from work (DAW) BLS (2004).

2. Methods

NIOSH sought contractors and tradespeople with experience developing and implementing ergonomics programs and interventions to attend the stakeholder meeting. The affiliations of the 39 industry attendees are shown in Table 2. In addition to the industry representatives, 17 ergonomics researchers from

Table 2
Sector affiliation of attendees

Stakeholder	Union	Contractor	Joint[a]
Electrical	3	7	1
Pipe	5	6	1
Sheet metal	2	6	1
Other[b]	1	4	2

[a]Joint labor-management organization.
[b]Construction industry representative not exclusively involved in mechanical or electrical specialities.

academia and government and 4 ergonomics consultants with experience in the construction industry participated in the stakeholders meeting. The stakeholder meeting format included presentations reviewing the scientific literature regarding WMSD risk factors and injury and illness data for the mechanical and electrical trades. The presentations were followed by trade-specific break-out sessions, allowing for detailed discussion of risk factors and control strategies. The break-out sessions, lasting more than 50% of the meeting time, were similar in structure to a focus group. Audio-recordings of the discussions were obtained for each session and used to prepare a written summary of each breakout session.

Contractors and tradespeople were assigned to meet with others in their respective trade or specialty, and researchers were assigned to a session according to their knowledge or interest in one of the trades. Each session met for six hours. Two facilitators were assigned to each breakout session to moderate and record the discussion. Facilitators were provided background materials and a suggested script to standardize the format and content of the discussions. Participants were asked to complete the five tasks shown in Table 3. The stakeholder meeting organizers viewed the first two tasks as 'warm-up' activities. These questions were derived from a study of trade-specific tasks representing a local building and construction market (Everett, 1997). Questions 3–5 were given priority during the stakeholder meeting.

2.1. Review the activities and basic tasks fundamental to each trade

Everett (1997) identified nine job activities and related tasks performed by southwestern Michigan union plumbers, HVAC/sheet metal workers, and electricians. Activities were defined as "all the field work which results in a recognizable, completed unit of work with spatial limits and/or dimensions." Tasks were defined as a "series of steps which comprise an activity." Each breakout session was allowed to add activities or tasks to the list, if there was no objection from a member of the group.

Table 3
Five tasks for breakout sessions

1	Review the activities (jobs) and tasks fundamental to each trade as described by Everett (1997)
2	Review the hazard risk rank assigned to an activity
3	Describe the context of the WMSD risk for each task
4	Describe currently available and used interventions for reducing WMSD risk
5	Identify potential interventions requiring further evaluation and tasks currently lacking an effective intervention

2.2. Review the WMSD risk rank

For each task, Everett (1997) evaluated workers' exposures to seven WMSD physical risk factors. Each risk factor was scored as (1) not present or insignificant, (2) moderate, or (3) high. The seven physical risk factors were repetitive exertions, static exertions, forceful exertions, localized mechanical stresses, posture stresses, low temperature, and vibration. Before the stakeholder meeting, an average risk score for each task was calculated using Everett's (1997) data and tasks in the upper third were ranked 'high' risk, the middle third 'moderate', and the lower third as 'no or low' risk. The average scores were used to facilitate discussion and were not intended to represent an absolute risk of the tasks within a trade or between the trades. Participants were told they could modify the risk rank for a task, if they believed the risk was over- or under-stated relative to other tasks and no stakeholder objected. Starting with the high risk tasks, participants were asked to consider the context of the hazard, the currently available interventions, and the need for future research and development issues.

2.3. Describe the context of the WMSD risk

For each task, participants were asked to identify the following usual and variable features of the WMSD risk: (1) the body areas at risk for developing WMSDs, (2) the specific risk factors, (3) the source of each risk factor, and (4) the task conditions affecting the intensity of the risk factor.

2.4. Describe currently available and utilized interventions

Participants were asked to describe the various interventions or best practices to control musculoskeletal loading that they had utilized or knew about. In many cases, participants provided their opinions regarding the effectiveness of an intervention and whether they believed further evaluation was needed.

2.5. Identify issues for future research and development

Participants in each of the breakout sessions were asked to identify tasks involving significant musculoskeletal loading for which an intervention was not currently available or for which a more effective intervention was needed.

3. Results

3.1. Activity and task review

Time constraints did not permit a full discussion during the breakout sessions of added tasks and activities. The results for each breakout session are described below.

3.1.1. Electrical trade activities and tasks

Three activities and three tasks were added to the initial list (Table 4). Three tasks were upgraded from the moderate to high risk and one task was reduced from high to moderate risk (Table 5).

3.1.2. Pipe trade activities and tasks

Three activities and three tasks were added to the initial list (Table 6). Risk was upgraded from the moderate to the high risk for two tasks and two tasks were reduced from the high to the moderate risk (Table 7).

Table 4
Electrical trades activities and tasks[a]

Activities	Task
Install conduit	Formulate work sequence Carry materials to work location Measure and layout Bend, align, position conduit Attach conduit to wall/ceiling Connect conduit to junction box Inspect work
Install wiring	Formulate work sequence Carry materials to work location Pull wires Strip end of wire Bend wire to proper location Connect wires Inspect work
Install lighting system and/or fixtures	Formulate work sequence Carry materials to work location Position fixture Connect fixture to wall/ceiling Inspect work
Install residential wiring[b]	Connect wires[b] Strip end of wire[b] Bend wire to proper location[b]
Install underground service[b]	
Install switch gears[b]	

[a]Unless otherwise described, activities and tasks are from Everett (1997).
[b]Added during the breakout sessions.

Table 5
Average WMSD risk for electrical trade tasks

Average risk	Task
High	Pull cable/wires Attach raceway to wall or ceiling[a] Position fixture Bend, align, position conduit[b] Connect wires[b] Carry materials to work location[b]
Moderate	Strip end of wire Connect fixture to ceiling or wall[c]
Low	Connect conduit to junction box Bend wire to proper location Inspect work Measure and layout

[a]'Raceway' substituted for 'conduit'.
[b]Previously ranked 'moderate'.
[c]Previously ranked 'high'.

Table 6
Pipe trades activities and tasks[a]

Activity	Task
Install pipe hangers	Formulate work sequence Carry materials to work location Measure and layout Drill holes Place hanger/fitting Screw/shoot into wall/ceiling Inspect work
Install domestic water pipes, sanitary sewers, gas pipes, etc.	Formulate work sequence Carry materials to work location Measure lengths of pipe Cut pipe Check for burrs Remove burrs, grind ends Move pipe to correct location Weld, solder, braze, screw, bolt Inspect work Position pipe[b] Test piping[b] Site clean-up[b]
Install fixtures	Formulate work sequence Carry materials to work location Measure and layout Drill holes Position fixture Attach fixture to wall/floor Inspect work
Install equipment[b]	
Install deck inserts (i.e., site prep)[b]	
Plan reading and detailing[b]	

[a]Unless otherwise described, activities and tasks are from Everett (1997).
[b]Added during breakout sessions.

Table 7
Average WMSD risk for pipe trade tasks

Average risk	Task
High	Place hanger/fitting
	Drill holes
	Screw/shoot into wall/ceiling
	Remove burrs, grind ends
	Join pipe[a]
	Lift and carry materials to work location[b]
Moderate	Attach fixture to wall/floor[c]
	Position fixture[c]
	Cut pipe
Low	Measure and layout
	Measure lengths of pipe
	Inspect work
	Formulate work sequence

[a]Previously 'weld, solder, braze, screw and bolt pipe' and 'moderate' risk.
[b]Previously 'lift and carry' and 'moderate' risk.
[c]Previously 'high' risk.

3.1.3. Sheet metal trade activities and tasks

Four activities and five tasks were added during the session (Table 8). The HVAC/sheet metal group assigned the high risk rank to all of the six tasks added to the list during their session (Table 9).

3.2. Risk context and interventions

Many of the installation and material handling tasks are similar for each of the trades. Three similar tasks described in each of the breakout sessions, which are common to each trade, have been combined and reported as: 'drill holes and shoot fasteners', 'place and install electrical and mechanical systems', and 'lift and carry materials and equipment'. The trade-specific results, i.e., related to tools or materials only used by the trade, will be reported at another time.

3.2.1. Drill holes and shoot fasteners

Commercial and industrial piping, HVAC components, and electrical conductors are frequently fastened to overhead hanging systems that have been secured to reinforced concrete or metal structural members. Mounting holes for system components, such as fasteners and all-thread rod, are drilled using rotary impact hammer drills (RIHD). Other systems can be installed using metal pins which are 'shot' directly into the ceiling or wall with powder actuated tools (PAT). Participants reported that musculoskeletal loading is present while drilling holes and shooting fasteners for the following body regions: the upper extremities (hands, wrists, and elbows), neck, back, shoulders, and knees. Risk factors reported included high forces generated by tools, including vibration and rotational

Table 8
Sheet metal trades activities and tasks[a]

Activity	Task
Install duct hangers	Formulate work sequence
	Carry materials to work location
	Measure and layout
	Drill holes
	Place hanger
	Screw/shoot into ceiling
	Inspect work
Install ductwork	Formulate work sequence
	Carry materials to work location
	Measure and layout
	Position duct section
	Connect ductwork to hanger/ceiling
	Inspect work
Install equipment	Formulate work sequence
	Carry materials to work location
	Measure and layout
	Connect equipment to ceiling/duct
	Inspect work
Assemble duct pieces in field[b]	Install flange/collar and tap-in/spin-in[b]
	Cut and trim duct joints[b]
	Assemble duct sections[b]
	Weld[b]
Demolition[b]	Cut and remove duct sections[b]
Move material to and within jobsite[b]	
Detail work and field design[b]	

[a]Unless otherwise described, activities and tasks are from Everett (1997).
[b]Added by stakeholders during the breakout session.

Table 9
Average WMSD risk for sheet metal trade tasks

Risk	Task
High	Drill holes
	Screw/shoot into ceiling
	Connect duct to hanger/ceiling
	Place hanger
	Position and connect duct pieces together[a]
	Assemble duct pieces in the field[b]
	Cut and trim duct joints[b]
	Weld[b]
	Move heavy equipment (rigging)[b]
	Cut and remove duct sections during demolition[b]
Moderate	Position and connect equipment to ceiling/duct
	Position duct section
	Carry materials to work location
Low	Measure and layout
	Inspect work
	Formulate work sequence

[a]Added by recommendation of a mechanical contractor before the stakeholder meeting.
[b]Task added and risk rank assigned by stakeholders during the breakout session.

and impact forces; physical exertion to hold and operate heavy tools; frequent and/or repeated tool operation; sustained non-neutral postures, and localized mechanical stress. Variable conditions reported to modify the actual hazard were the location of the work, e.g., ceiling, floor; type of building material drilled, e.g., concrete; tool design, performance, and maintenance; job specifications, e.g., number of holes to drill; and building site management (e.g., level of communication and coordination among contractors and trades).

Interventions reported to be in use by some contractors and/or suggested by stakeholders to reduce the risk posed by drilling holes and shooting fasteners are described in Table 10. Some interventions, such as the use of embedded concrete inserts or beam clamps, are upstream design decisions outside the authority of the contractor or trades person. Most participants supported the following administrative controls to reduce musculoskeletal loading: worker training programs, i.e., body mechanics; job rotation and micro-breaks; physical conditioning, i.e., stretching programs; pre-job planning and hazard analysis; and optimizing communication and coordination among contractors and trades on the building site.

Suggested interventions that participants believed required further evaluation included the use of the 'neck pillow' for overhead work, the use of tool suspension and balance systems on work platforms, and alternative triggering devices for power tools, i.e., foot pedals. Strong support was expressed for development of an adjustable stand to hold and advance a rotary impact hammer drill during overhead drilling.

3.2.2. *Place and install mechanical and electrical systems*

In commercial and industrial buildings, mechanical and electrical systems are supported by hangers, tracks, or trays attached to ceilings or walls. Powered screw guns and manual tools are used to assemble hanging systems and to tighten the fasteners. System components must be lifted, positioned and held in place when they are attached to the hangers, tracks or trays.

Participants reported that musculoskeletal loading is present while placing and installing mechanical and electrical systems for the following body regions: upper extremities (e.g., hands, wrists, and elbows), neck, back, shoulders, and knees. Risk factors reported included repeated hand movements, repeated and sustained non-neutral body postures, exposure to tool reaction forces

Table 10
Suggested ergonomics interventions to reduce musculoskeletal loading during drilling holes and shooting fasteners

Suggested ergonomics interventions			
Problem/musculoskeletal load	Electrical	Piping	Sheet metal HVAC
Install anchors for hanging system in concrete[a,b,c,d,e,f,g]		Specify embedded concrete inserts (i.e., Unistrut, Anvil, etc) or beam clamps, caddy clips	Specify embedded concrete inserts (i.e., Unistrut, Anvil, etc) or beam clamps, caddy clips Place minimum number of hangers required
Operate rotary-impact hammer drill[a,b,c,f]	Use clutch driven drill to control torque Use sharp bits Use low vibration tools Use vibration damping gloves[h]	Use clutch driven drill to control torque Use sharp drill bits Use vibration damping gloves Implement a tool & bit maintenance program	Use drill with side arm to control torque Use low vibration tools; Implement program to identify and purchase tools on performance criteria
Operate powder actuated tool overhead[b,c,d,f]		Extension pole and remote triggering;	Use extension pole and remote triggering
Drill overhead	Support head with neck pillow Work on platform or scaffold	Use drill bit extender Suspension and balance system for tool	Use drill bit extender Work on powered lift or scaffold
Work overhead[b,c,e,g]	Work on powered lift or scaffold	Work on powered lift or scaffold	Work on powered lift or scaffold
Standing on concrete[b,e]	Stand on anti-fatigue mat	Stand on anti-fatigue mat or use shoe inserts	
Working at floor level[b,d,e]			Use knee pads

[a]Repetitive exertion.
[b]Static exertion.
[c]Forceful exertions.
[d]Localized mechanical stresses.
[e]Postural stress.
[f]Vibration.
[g]Other, i.e., safety.
[h]Not a reliable control for hand-arm vibration exposure.

(e.g., vibration, rotation), physical exertion while holding and positioning system components, and localized mechanical stress. Variable conditions reported to modify musculoskeletal loading included the work location (e.g., ceiling, floor), equipment used to reach ceiling work (e.g., work platform vs. ladder), weight and size of system components, building design and specifications (e.g., type of fastening system); work space size and clearance, the presence and/or effectiveness of job site communication and coordination among the contractors and trades.

Interventions reported to be in use by some contractors or suggested by stakeholders to reduce the risk posed by placing and installing mechanical and electrical systems are shown in Table 11. Again, interest was expressed for engineering design solutions to reduce musculoskeletal loading, such as embedded concrete inserts. Most administrative controls described in the previous section were considered potentially useful e.g., body mechanics training; job rotation and micro-breaks; physical conditioning, i.e., stretching programs; pre-job planning and hazard analysis; and optimal communication and coordination among contractors and trades on the building site. Suggested interventions requiring further evaluation included the 'neck pillow' and using powered work platforms to lift, hold and position materials during ceiling installation.

3.2.3. *Lift and carry materials and equipment*

Building materials and equipment used by the mechanical and electrical trades must be unloaded at the job site, transported to a storage location, stored until needed, and transported to the location where they will be used. The need to accommodate continuous change on the building site can result in repeated handling and transport of materials and equipment. Workers lift and transport materials and equipment by hand and with assistance from non-powered and powered equipment.

Participants reported musculoskeletal loading is present while lifting and carrying materials and equipment for the following body regions: back, shoulders

Table 11
Suggested ergonomics interventions to reduce musculoskeletal loading during placing and installing mechanical/electrical systems

Suggested ergonomics interventions			
Problem/musculoskeletal load	Electrical	Piping	Sheet metal HVAC
Intensive manual hand tool use[a,b,c,d]	Use cordless power tools	Select tool with best design for task	Use power tool when possible
Work overhead[b,c,e,g]	Work on powered work platform or scaffold	Work on powered work platform or scaffold	Work on powered work platform or ladder platform
Install anchors for hanging system in concrete[a,b,c,d,e,f,g]		Specify embedded concrete inserts (i.e., Unistrut, Anvil, etc.) or beam clamps, caddy clips Facilitate worker physical conditioning, i.e., stretching programs Take short ('micro') breaks	Specify embedded concrete inserts (i.e., Unistrut, Anvil, etc) or beam clamps, caddy clips Place minimum number of hangers
Set threaded rod anchor with manual tools[a,b,c,d,e,f,g]		Use ratchet with open socket to tighten nuts Use split or button nut	Use power drill to tighten anchors and set nut Use ratchet with open socket to tighten nuts Use split or button nut
Manually lift, position and hold system components[a,b,c,d,e,f,g]	Use powered and mechanical devices to raise materials and equipment Use fixtures to hold, lift and position materials	Use powered and mechanical devices to raise materials and equipment Use fixtures to hold and position work materials, i.e., "v" fixture for pipe	Use powered and mechanical devices to raise materials and equipment Use fixtures to hold and position work materials, i.e. half-moon fixture for circular duct Use magnets or suction cups with handles to position duct
Using floor as work surface[c,d,e,g]	Use portable work table		Keep work off the floor

[a]Repetitive exertion.
[b]Static exertion.
[c]Forceful exertions.
[d]Localized mechanical stresses.
[e]Postural stress.
[f]Vibration.
[g]Other, i.e., safety.

and upper extremities. Variable conditions reported to modify musculoskeletal loading included the condition of walking/working surfaces (e.g., clear aisles, flat surface); the location and system used to store materials and equipment (e.g., distance from installation area); the availability and maintenance of material handling equipment; and the nature of communication and coordination among contractors and trades.

Interventions reported to be in use by some contractors or suggested by participants to reduce the risk posed by lifting and carrying materials and equipment are shown in Table 12. In addition to the administrative controls previously described, participants suggested the use of programs to optimize building site organization and housekeeping. Participants described the need for intervention effectiveness research to evaluate the use of lifting programs, including weight limits, physical conditioning, i.e., 'stretch and flex' exercise programs, and workplace organization and housekeeping programs. Other interventions discussed included ergonomics design of material packaging and containers, e.g., weight and dimensions; hand-to-object coupling; and weight labeling.

4. Discussion

At the time of the stakeholder meeting only the states of California and Washington had adopted occupational ergonomics regulations which covered building and construction (WISHA, 2000; CA DIR, 2004) and the Occupational Safety and Health Administration (OSHA) had not yet announced plans to develop voluntary ergonomics guidelines (BNA, 2002). 80% of the M/EI contractors and tradespeople attending the stakeholder meeting were from California, Oregon, and Washington states. Stakeholders from the states that had adopted ergonomics regulations and from Oregon,

Table 12
Suggested ergonomics interventions to reduce musculoskeletal loading during manual material handling

Suggested ergonomics interventions			
Problem	Electrical installation	Pipe installation	HVAC system installation
Lift and transport materials and equipment[b,c,d,e,g]	Use fork lift or small lift truck Use air cushion for heavy objects (i.e., transformer) Transport materials on pallets	Material handling equipment, i.e., pipe carriage w/ offset extended handle, pipe stand with casters, carts, cranes, etc. Use crane to lift pipe and materials between floors Use a roller conveyor system to position heavy objects in smaller areas Warm-up stretching programs Establish weight limits, e.g., NIOSH (1994)	Material handling equipment, pallet jack, forklift, dolly, crane, roll-o-lift, roof cart, sheet rock cart Use pulley and chainfall to lift equipment Use a raised roller conveyor system to move and position large duct for installation Warm-up stretching programs
Push and pull rolling stock, i.e., gang box, pipe[a,b,g]	Use ramps and metal plates on job site Maintain access for material handling equipment	Maintain access for material handling equipment	Use rolling stock with appropriate wheels and casters for the work surface
Carry materials and equipment[b,c,d,e] Establish weight limits, e.g., NIOSH (1994).	Use manual lift and carry assists	Use manual lift and carry assists, i.e., slings, shoulder guards, etc.	Fabricate handles for equipment to improve hand-to-object coupling Fabricate carts for special purposes, i.e., hold welding equipment and cylinder
Material and equipment storage[a,c,e,f]	Off-ground storage of materials and equipment, e.g., pipe racks, pallets, etc.	Off-ground storage of materials and equipment, e.g., pipe racks, pallets, etc. Bag and tag by use location	Use vertical or cabinet style gang box

[a]Repetitive exertion.
[b]Static exertion.
[c]Forceful exertions.
[d]Localized mechanical stresses.
[e]Postural stress.
[f]Vibration.
[g]Other, i.e., safety.

where many contractors work in California or Washington, were more likely to have had experience addressing the concerns of these ergonomics regulations. The stakeholders participating in the stakeholder meeting were believed to have above average knowledge and/or experience in implementing ergonomics interventions in the M/EI construction sectors, although the level of knowledge and experience varied. Two contractors located in Oregon had participated in an ergonomics intervention research project on a new construction site (Hecker et al., 2000). One of these contractors had a history of empowering employees to develop job-specific ergonomics interventions. A large California electrical contractor had developed and implemented an ergonomics job hazard analyses program and provided ergonomics awareness training to employees. A Midwestern HVAC systems contractor had implemented extensive ergonomics change in his fabrication shop and, to a lesser extent, on building sites. Another contractor had participated in an ergonomics demonstration project in Washington State. The experience of most contractors and trades people, however, was limited to the use of specific tools, equipment or training. Only one sector represented at the stakeholder meeting, HVAC system fabricators and installers, had developed a joint labor and management ergonomics education and training program, which had been available for use in the United States and Canada (SMOHIT, 1999).

Although researchers participated in the breakout sessions, the results represent the knowledge and experience of the participating contractors and tradespeople. Breakout session facilitators understood that contractors and trades people were to play the primary decision making role during the stakeholder meeting. The extent to which researchers' participation influenced final decisions is not believed to be significant.

4.1. Activity and task review

Job activities ($n = 10$) and tasks ($n = 11$) were added to the initial lists. Some additions to the activity lists were redundant or best described as tasks. Important additions, however, included 'install underground service' and 'install switch gears' (electrical systems), 'install equipment' (piping systems), and 'assemble duct pieces on jobsite' (HVAC/sheet metal systems). The HVAC/sheet metal group spent more time describing the activities and assigning a risk rank to the added tasks than did the other groups. All of the added tasks were assigned the high risk rank and five were attributed to the 'assemble duct pieces in the field' activity. It is interesting to note that during the stakeholder meeting, a contractor had reported developing and using a jig to assist the assembly of large duct pieces in the field. The jig was developed to reduce the amount of manual handling and sustained awkward postures usually required for the activity. The added activities and tasks indicate that Everett's (1997) original list, drawn from a local construction market, can be expanded to include activities occurring in other construction markets.

4.2. Context of WMSD risk

For the most part, the answers concerning WMSD risk provided little new information, which was anticipated by the organizers. The questions concerning body areas potentially affected by WMSDs and the specific risk factor were intended to promote discussion and determine whether there were significant disagreements among the participants. No serious disagreements were reported to have taken place during the breakout sessions, while most industry representatives demonstrated a fundamental understanding of the association between workers' exposures to physical risk factors and the WMSD that could result. This level of understanding was expected, as organizers had primarily invited industry representatives with previous experience implementing ergonomics interventions.

Organizers assigned greater importance to the questions related to tasks (i.e., source of musculoskeletal loading) and the variable conditions that can modify the overall risk associated with a task. Conditions described included those that were both dependent and independent of the task of interest. Dependent conditions were related to the tools and equipment, building design, and job specifications. Conditions independent of the actual task were related to the physical building site, weather conditions, work organization, activity/task sequencing, and management practices on building sites. Many of the dependent and independent conditions were described as outside the control of the contractor and tradesperson. Building site management was described as a key concern, due to the difficulties coordinating the activities of multiple contractors and trades working on the same building site. The conditions participants described were similar to the root causes identified by Haslam et al. (2005) for 94% of the construction accidents they investigated, such as construction design and processes, project management, risk management, client and economic influences, and safety education and training.

4.3. Currently available interventions

Participants recommended many of the same or similar interventions to reduce musculoskeletal loading for high and moderate risk work tasks shared by the three trades. Most interventions described were engineering or administrative controls of the types described by Hsiao and Stanevich (1997). Although several types of personal protective equipment were discussed, these

were not embraced by most participants. One exception was the use of 'anti-vibration' gloves to attenuate hand-arm vibration exposures while operating power hand tools, e.g., rotary impact hammer drill. The perception of many stakeholders regarding the effectiveness of anti-vibration gloves may exceed the actual benefit. Although a few anti-vibration glove designs can reduce vibration transmitted to the hand, the reduction is highly dependent on the tool vibration spectrum and the reductions are greater for higher frequency vibration levels (Dong et al., 2003). A hierarchy of controls is generally accepted that favors the use of engineering controls to prevent WMSDs, which addresses the presence or intensity of a physical risk factor (NIOSH, 1997). Examples of engineering controls recommended during the stakeholder meeting include the redesign of tools and building materials and the use of mechanical material handling equipment, powered lifts, and concrete embedded fastening systems. Most industry representatives appeared to recognize that these were the most effective means to eliminate or reduce exposures to WMSD risk factors.

There was wide support expressed by stakeholder meeting participants for the use of administrative controls, which have been defined as management dictated work practices and policies (NIOSH, 1997). Administrative controls attempt to eliminate or reduce the exposure to a risk factor using workplace rules to change or modify behavior (NIOSH, 1997). Physical conditioning programs and lifting/biomechanics training programs were seen as means to reduce the individual workers' exposure to a physical risk factor. Many industry stakeholders provided anecdotal evidence to support the use of physical conditioning and training programs, which were widely supported by both contractor and trade participants. Stretching programs were favorably discussed in all breakout sessions despite the lack of objective evidence demonstrating their effectiveness in reducing WMSD risks (Hess and Hecker, 2003).

Programs to improve planning and coordination of work activities on construction sites were frequently recommended. Effective planning and coordination of the various contractor and trade activities were considered critical to positively impacting building site working conditions (e.g., material staging locations, housekeeping, work sequencing) and, correspondingly, the likelihood that ergonomics interventions could be feasibly adopted (e.g., use of carts and other material handling equipment). Several participants, including researchers, advocated participatory ergonomics programs, but the concept was not familiar to many of the stakeholders. One study of a participatory ergonomics program for construction and maintenance installation workers by de Jong and Vink (2002) reported the successful adoption of several of the same interventions described during the stakeholder meeting to control exposures to WMSD risk factors associated with manual material handling, sustained non-neutral working postures, and kneeling. Interventions directed at musculoskeletal loading during overhead work were not described, although overhead work had been identified in a risk inventory.

4.4. Future intervention work

All three of the groups described a need for future research to determine whether certain interventions were effective. Evaluations were recommended for interventions best described as personal protective equipment, e.g., neck pillow, shoulder guard, and for modifications to existing equipment, e.g., material-support fixtures for an aerial lift (a.k.a. man-lift). In the latter case, a major concern was the introduction of a safety hazard from loading the aerial lift which could lead to insurance/liability issues. Strong interest was expressed for a stand that could support a rotary impact hammer drill during overhead drilling, a job that had been described as especially demanding. A similar interest, however, was not found in a postal survey conducted by Andersson (1990), in which few Swedish electricians reported using or requesting a stand to support a hammer drill for overhead work that had been available and publicized for 7 years.

The presence of WMSD risk factors and the desirability of controlling workers' exposures to them were acknowledged by all participants, as were the difficulties characteristic of building and construction activities. Participants underscored the limits of individual contractors and tradespeople to significantly affect building design, specify materials and components, and influence site management systems, relative to building owners, architects and designers, and engineers. Building and construction sites are multi-employer work sites involving a 'temporary alliance among independent organizations' (Slaughter, 1998). The interventions that can be implemented by contractors or tradespeople are limited in part by the impact they will have on the other contractors/trades working on the site. Slaughter (1998) distinguishes between 'modular' innovations that can be introduced with minimum affect on the work of other contractors/trades on the same site and 'architectural' and 'system' innovations requiring increasingly complex integration with site activities. Modular innovations described in this report tend to reduce exposures to one or more risk factors, while an architectural innovation, changes the nature of the activity for both the ME/I trades and other trades. One example of an architectural innovation is the use of embedded concrete inserts for hangers used to support mechanical or electrical systems on ceilings of commercial and industrial buildings. Instead of using a rotary impact hammer drill to drill

the holes in reinforced concrete ceilings for the anchors that will support mechanical or electrical systems, the concrete inserts are installed on the forms used to support newly poured concrete. When the forms are stripped away from the concrete, threaded rods or bolts used to support the systems are fastened to the inserts. In this case, installation workers would be relieved of sustained repetitive overhead use of a hammer drill, although another trade would be required to place the inserts on the concrete forms. Architectural and system innovations, like those described and supported during the stakeholder meeting, must be addressed during the early stages of the conception and design of the structure. The stakeholders concurred with Hecker et al. (2000) that "significant ergonomic improvements", such as the adoption of architectural and system innovations that address WMSD risk factors, requires the support and involvement of building owners, architects and designers, and manufacturers.

Participants also reported that the introduction and acceptance of any ergonomics intervention was sensitive to the initial costs and its impact on productivity and workers' craft traditions (i.e., controls reducing the skill requirements of a task). Although there was agreement regarding the need to evaluate the effectiveness of new interventions, many participants said they would consider ergonomics solutions based on personal or anecdotal verification, suggesting that more rigorous evaluation may not always be necessary for contractor trial and eventual adoption.

Stakeholders expressed considerable support for the use of both engineering and administrative controls and, in general, were skeptical of the effectiveness of personal protective equipment to control WMSD risk factors. Support for the use of engineering controls, including changes in building materials and design, may be reflective of an understanding among some stakeholders that these innovations can result in a favorable impact on productivity, as well as reduced exposure to WMSD risk factors. Some may have expressed support for these innovations knowing that they have little control over their adoption and, therefore, requiring them to do little or nothing to ensure they are adopted. Conversely, administrative controls, such as training and physical conditioning programs appear intuitive to many stakeholders and can be implemented by them. For some, these programs may also reflect current beliefs and attitudes regarding the role of worker behavior in both promoting and preventing injury and illness. Improvements in building site management and communication, which were strongly supported by all stakeholders, could increase the influence of individual contractors on a building site and reduce many barriers to effective implementation of ergonomics interventions, as well as inefficiencies that have a negative affect on schedules and productivity.

5. Conclusion

The stakeholder meeting succeeded in identifying the types of voluntary control measures that had been implemented by M/EI contractors, the task-specific hazards for which control measures needed to be developed or refined, and the perceived barriers to improving hazard controls. Asking stakeholders to answer a series of semi-structured questions in facilitated trade-specific breakout sessions was essential to ensuring broad participation and a more focused discussion and would likely not have occurred without the use of the break-out sessions. Meeting in the break-out sessions, stakeholders answered the questions using their own terminology and, in addition to describing what they believed, they also had an opportunity to explain why they believed it. Both factors allowed researchers to gain a deeper understanding of the issues. Consequently, stakeholders provided many practical recommendations during the break-out sessions, including a variety of trade-specific practices not described in this paper, which will be published later and disseminated among M/EI contractors.

Several limitations of the stakeholder meeting should be noted. First, a well defined threshold of ergonomics intervention experience had not been established before recruiting participants. As a result, the range of experience was broad, which may have increased the time spent discussing basic issues, rather than describing the development and implementation of the interventions in more detail. Second, non-supervisory tradespeople were under-represented in the stakeholder meeting. The tradespeople brought to the stakeholder meeting by contractors were all supervisory personnel, though in many cases they were also members of a trade union. Non-supervisory workers may have concerns and experiences distinct from supervisors, which need to be heard. Given the difficulty assuring meaningful representation by non-supervisory workers at an extended stakeholder meeting, alternative methods need to be considered to solicit their input. Finally, although the stakeholder meeting succeeded in answering important questions regarding the current use of ergonomics interventions in the M/EI sectors, the number of stakeholders participating in the stakeholder meeting was small. Future work in this area could investigate the diffusion of ergonomics 'best practices' throughout the M/EI sectors by soliciting responses from a larger sample of stakeholders through the use of postal questionnaires and focus groups.

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