Available online at www.sciencedirect.com
SCIENCE DIRECT
International Journal of Industrial Ergonomics 34 (2004) 319–333
International Journal of Industrial Ergonomics
www.elsevier.com/locate/ergon

Task content and physical ergonomic risk factors in construction ironwork

Martin S Forde[a,b,*], Bryan Buchholz[a]

[a] Department of Work Environment, University of Massachusetts Lowell, 1 University Avenue, Lowell, MA, 01854, USA
[b] Department of Public Health & Preventive Medicine, St. George's University, P.O. Box 7, St. George's, Grenada, WI, USA

Received 12 November 2002; received in revised form 8 March 2004; accepted 20 April 2004

Available online 20 June 2004

Abstract

Construction ironwork (CI) has been identified as a trade wherein the exposures to ergonomic risk factors are high. In this study, quantitative exposure assessments for seven specific ironwork tasks selected from the four main specialties of CI—machinery moving/rigging, ornamental, reinforcing, structural—were performed. A total of 13,821 observations were made using the work-sampling, specialty-task-activity-based analysis method called PATH (posture, activity, tools, and handling) and a taxonomy developed specifically for CI. The PATH data provided specialty-task-activity estimates of the percentage of time ironworkers spent in specified postures of the trunk, arms, and legs, and also gave estimated frequencies of manual materials handling activities as well as 11 other predefined activities. Depending on the specialty-task-activity performed, results showed that ironworkers spent anywhere from 13% to 48% of their work time in non-neutral trunk postures; worked with one or both arms at or above shoulder level 6–21% of the time; and stood on uneven/unstable work surfaces 3–53% of the time. The type of activity performed was consistently found to be a major predictor of the frequency of work time spent in non-neutral postures for the trunk, legs, and arms.

Relevance to industry

These results can be used to target hazardous activities in CI such as rebar and structural ironwork and confirms the need for specialty-task-activity-specific information within each construction trade on exposures and worker activities so that the most appropriate ergonomic interventions can be designed and implemented.

Keywords: Ironwork; Construction ironwork; Exposure assessment; Ergonomic risk factors

1. Introduction

Recent studies and statistics have shown that the rates of musculoskeletal injuries and disorders among workers in the construction trades are much higher when compared to those working in other industries (Schneider, 1997; CPWR, 1996).

*Corresponding author. Tel.: +1-473-44-4175; fax: +1-473-444-1219.
E-mail address: mforde@sgu.edu (M.S. Forde).

0169-8141/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.ergon.2004.04.011

According to the US Bureau of Labor Statistics, construction workers suffer work-related injuries and illnesses at a rate of 7.9 cases per 100 equivalent workers compared to the all-industry average of 5.7 (BLS, 2001). Construction workers had the highest rate of injuries of 7.8 versus that all industry average of 5.4 (BLS, 2001). In general, construction workers are at a high risk of developing work-related musculoskeletal disorders (WRMSDs) that are associated with exposure factors in this work environment (Holstrom et al., 1993; Guo et al., 1995; Kisner and Fosbroke, 1994; Schneider and Susi, 1994).

Despite the high prevalence of ergonomic risk factors in construction work (Schneider and Susi, 1994; Schneider, 1997; Kisner and Frosbroke, 1994), research has been limited in this industry. This can be attributed mainly to logistical reasons. Specifically, some of the main problems faced by researchers seeking to design studies for this segment of the working population are high task variability, highly irregular work periods, constantly evolving work environments, and high worker mobility. As a result, systematic and comprehensive *trade*- and *task-specific* investigations of the relationship between ergonomic exposures and WRMSDs have been undertaken for only a limited number of trades (e.g., Lindstrom et al., 1974; Wickstrom, 1978; CPWR, 1994; Riihimaki, 1985; Cook et al., 1996). Just as office- or factory-based exposure information is often inapplicable to the dynamic construction work environment, so to, each construction trade and the major tasks associated with it often present different and unique ergonomic challenges to the worker. Trade- and task-specific information on tools, exposures, worker tasks and work conditions is likely to prove most useful in designing and selecting the most appropriate prevention measures to minimize the incidence of WRMSDs among construction workers.

The term 'construction' ironwork (CI) (also commonly referred to as 'outside' ironwork) is used to distinguish this type of ironwork from 'shop' or 'fabricating' ironwork which, unlike CI, tends to take place indoors in more structured, factory-like settings. In general, CI involves the erection of structural steel, placement of reinforcing bars in concrete structures, moving heavy machinery, rigging and erection of equipment and scaffolding, installation of fabricated building components, and welding and cutting. In the United States, CI is sub-classified around four main specialties (Robertson, 1975): (1) structural ironwork (SIW), (2) reinforcing ironwork (RIW), also know as rod or rebar work or concrete reinforcement work, (3) ornamental ironwork (OIW), and (4) machinery moving/rigging ironwork (MMRIW).

Each CI specialty consists of key tasks and activities that are specific to that specialty (Table 1). Those entering the ironwork trade are required to undertake a 3-year apprenticeship training program wherein they are taught and exposed to all four ironwork specialties (Robertson, 1975). On completion of the training program, the ironworker gains "journeyman" status and begins to specialize in one or two of the above CI specialties. Journeymen can, however, and do regularly change their specialty based on job requirements and current job market demands.

A few studies that have specifically collected ergonomic exposure data on CI (e.g., Forde, 2000a,b; Lindstrom et al., 1974; Hart and Link, 1991). These studies have found that typical of CI is that it requires the ironworkers to lift, carry, and manipulate heavy loads; work in severely cramped

Table 1
Representative list of major tasks commonly performed by construction ironworkers within each CI specialty

Trade type	Specialty	Tasks
CI	MMRIW	Heavy equipment lifting
		Crane assembly
	OIW	Door installation (e.g., revolving door)
		Window installation
		Finishing work (e.g., decorative sidings, railings, etc.)
	RIW	Pre-cast concrete assembly
		Rod work
		Caisson cage construction
	SIW	Structural steel assembly
		Bolt and nut assembly
		Bolting
		Decking (floor) installation

spaces or sustained awkward postures; work with their arms overhead; use heavy, vibrating pneumatic tools to which they must apply large forces and hold in static positions; and work at great heights while constantly exposed to the elements such as rain, snow, ice, wind, and temperature extremes. In other studies, the focus has been mainly on RIW as it relates to low back pain/disorder outcomes (e.g., Lindstrom et al., 1974; Nummi et al., 1978; Saari and Wickstrom, 1978; Wickstrom, 1978; Riihimaki et al., 1990; Riihimaki et al., 1989; Riihimaki, 1985; Nurminen, 1997; Buchholz et al., 2003). It appears that no published studies have examined the ergonomic exposure profiles for other CI specialties.

In general, it is clear that construction ironworkers are exposed to many ergonomic hazards. What is not clear, however, is whether these hazards remain the same across CI specialties (or even within a particular CI specialty, across activities) in terms of frequency, intensity, and duration. Given the paucity of information on the ergonomic exposures profiles for each CI specialty, the goal of this research study was to provide specialty-task-activity-based ergonomic exposure estimates for each of the four main specialties of CI. These exposure profiles could then be used to (i) target those CI specialty-task-activities that pose the greatest risk to ironworkers, and (ii) inform the development of workable and cost-effective interventions, including training materials.

2. Methods

2.1. Subjects and data collection sites

All workers observed in this study were union ironworkers with the majority belonging to Local 7, South Boston, MA, USA, of the International Association of Bridge, Structural and Ornamental Iron Workers. The number of ironworkers observed varied for each observed task and was determined by such factors as the number of workers on the site at the time data collection took place and worker visibility to the coder making the observations. Days and times for data collection were determined by such logistical factors as when the task was scheduled and availability of researchers to go take observations.

Data were collected at five construction sites over a 19-month period spanning from August 1998 to February 2000. The sites observed in this study were either heavy highway construction sites or large, commercial building sites.

2.2. Construction ironwork tasks observed

Due to several logistical reasons such as access to construction sites in the Boston area and the range of CI tasks being performed on these accessible sites during the data collection period, seven specific CI tasks were chosen to be observed. For RIW and SIW, the tasks chosen for observation are frequently performed by ironworkers working in these specialties. For OIW and MMRIW, the observed range of possible tasks was limited. The tasks observed in these CI specialties were very specific and are not necessarily typical of these CI specialties as a whole.

The seven CI tasks for which ergonomic exposure data were collected were MMRIW (Crane Assembly), OIW (Finishing), OIW (Revolving Door installation), RIW (Caisson Cage construction), RIW (Rod Work), SIW (Building erection), and SIW (Struts installation). Data on RIW(CC), RIW(RW), and SIW(S) were collected on highway construction sites and data on SIW(B), MMRIW(CA), OIW(F), and OIW(RD) were collected on building construction sites. A brief description of the work done and the sites involved is given in Table 2.

2.3. Exposure assessment

Due to the highly dynamic and unstructured nature of construction work, characterization of the ergonomic exposure profiles associated with various construction trades has proven to be challenging (Buchholz et al., 1996). When work is non-cyclical or the work cycles are long and irregular, the work needs to be observed over an extended period of time in order to accurately quantify the proportion of time a worker may be exposed to a specified risk factor (Paquet, 1998).

Table 2
Description of types of CI tasks observed and the type of construction site

Specialty	Task	Site type	Description of task
MMRIW	Crane assembly (CA)	Building	Extension of the boom on a crane by adding another 160 ft section
OIW	Finishing (F)	Building	Installation of brackets and plates for decorative aluminum facing along the upper wall of an entrance as well as hand railing at a subway station
	Revolving door (RD)	Building	Assembly and installation of a revolving door
RIW	Caisson cage (CC)	Highway	Construction of circular caisson cages from stretched out coils of rebar and supported by lengths of straight rebar
	Rod work (RW)	Highway	Laying down and tying of rods for the base and sides of an underground access tunnel
SIW	Building (B)	Building	Assembly of steel columns, girders, and cross beams, bolting, and decking installation
	Struts (S)	Highway	Installation of struts to support overhead concrete decking for an underground tunnel

Because of this, ergonomic exposure assessment protocols based on work sampling strategies with observations taken over a representative time period have been found to be well suited for accurately and conveniently capturing valid estimates of ergonomic hazards associated with construction work (Kivi and Mattila, 1991; Punnett and Paquet, 1996; Buchholz et al., 1996; Paquet, 1998).

The work-sampling, specialty-task-activity-based method called PATH (posture, activity, tool, handling) was chosen and used to provide quantitative exposure estimates for the seven CI tasks observed in this study. The PATH protocol has been used to evaluate ergonomic exposures in several construction trades (Buchholz et al., 1996; Punnett and Paquet, 1996; Paquet et al., 1996; Buchholz et al., 2003) as well as in non-construction sectors (Pan et al., 1999). A full description of the PATH protocol has been published elsewhere (Buchholz et al., 1996).

Using information gained from prior ergonomic job analyses (EJAs) (Forde, 2002a,b), a template was created to code CI observations for PATH. The taxonomy was organized hierarchically, with CI divided first into four major specialties and then into key tasks. Table 1 lists the four major CI specialties along with representative tasks associated with each.

For the trunk postures, non-neutral trunk postures were defined as all trunk postures other than 'Neutral'; non-neutral arm postures were defined as all arm postures other than 'Elbows below shoulder'; non-neutral leg postures were defined as all leg postures other than 'Stand (stable/even).'

Nine of the most commonly observed activities across all tasks were identify and used to specify worker activity. In addition to these commonly observed activities, two other activities codes were used: the code 'Other activity not specified' was used for activities observed other than the nine pre-defined activities and the code 'In between activities' was chosen if at the precise moment of data capture the worker was not doing any of the nine pre-defined activities listed on the PATH template, yet it was clearly evident that just prior to coding he was performing one of the other activities listed or was just about to do so.

Manual material handling (MMH) activity codes were used to capture activities that involved the manipulation of work materials or required a force exertion to accomplish a particular activity. Therefore, handling activities like lifting, lowering, pushing, pulling, dragging, guiding, carrying, holding, and using forceful motions to dislodge or position an object were captured by the MMH codes. If an MMH activity was observed, additional information such as how close the load was to the body ('Elbows close to body (shoulder flexion $<45°$)' or 'Elbows far from body (shoulder flexion $>45°$) and the load's estimated weight (<10 lb, 10–50 lb, >50 lb)) were recorded. The height (work zone) at which the activity was executed was recorded only if the ironworker performed a pre-defined activity. Three work heights were defined: (i) below knee height; (ii) from knee to waist; and (iii) above waist height.

For any given data collection session, typically a crew of workers was selected and followed. The actual selection of workers for observation was based on how easy it was to: (i) observe what they were doing; (ii) properly assess their postures; and (iii) follow their movements as they moved from point to point in the performance of their tasks. Prior to the start of PATH coding, each worker in the work crew was first assigned a number. Each coder pre-determined a sequence of workers to code by randomly selecting from the available worker numbers. Then at set time intervals ranging from 15 to 30 s depending on coder level of skill, each coder using his/her pre-determined worker sequence, took a 'mental snapshot' of the worker's posture, the activity being performed, MMH activity (if any), and the location at which the work was done in relation to the worker's height (for pre-defined activities). All this information was then recorded (coded) on the PATH coding sheet along with the worker's assigned number. For the next observation, another worker was randomly chosen, observed, and coded. Selected workers were therefore observed repeatedly at random times throughout the day over sampling periods that ranged from 3 to 6 h in length.

2.4. Data analysis strategy

Data from the CI-PATH coding sheets were entered into a spreadsheet and checked for errors. The cleaned data were then analyzed using the software package Stata (Stata Corporation, 1999) and the frequencies of exposures (i.e., percentage of time exposed) to such ergonomic factors as non-neutral postures and loads handled were determined. The frequency of each exposure was calculated as follows:

$$\text{Frequency} = \frac{n_e}{N},$$

where Frequency is the estimated as the proportion of time workers' exposure to a particular ergonomic factor, n_e is the observed number of observations with exposure, and N is the total number of observations.

In order to determine whether ergonomic hazard profiles remain the same across CI specialties (or even within a particular CI specialty, across activities) in terms of frequency, intensity, and duration, cross-tabulations using the chi-squared statistic were done for each activity with respect to posture (trunk, arms, legs), work height, and MMH activity. This would allow one to determine the significance of activity on these variables. Additionally, selected multiple concurrent exposures were examined (e.g., the percentage of time a worker spent in an non-neutral posture while performing a specific activity) to provide activity-specific estimates of exposure frequencies.

3. Results

A combined total of 13,821 PATH observations were taken on seven CI tasks (Table 3). The number of workers observed for a given task varied from 2 for OIW(F) to 12 ironworkers for RIW(RW). The number of days taken to collect data varied from 2 to 9 days. Figs. 2–5 shows the fraction of work time spent in various non-neutral postures for the trunk, arms, legs, and work heights, respectively, for the seven CI tasks observed in this study.

3.1. Overall PATH results

For all CI tasks combined ($n = 13,821$), non-neutral trunk, arm, and leg postures were observed 39%, 13%, and 79%, respectively, of observations made.

Using a chi-squared test, all posture categories differed significantly between CI specialties ($p<0.001$). The frequency of non-neutral trunk posture was the highest for RIW (44%) and SIW (43%); the highest observed non-neutral arm posture was for RIW (18%); and the highest non-neutral leg posture was observed for SIW (95%) and RIW (82%) (Table 4).

Lifting and lowering MMH activity frequencies were approximately the same ($\leqslant$5%) for all CI

Table 3
Percentage of work time observed for ironworkers spent working in various postures, MMH activities, activities, and work heights for seven CI tasks

	Ironwork specialty (task)						
	MMRIW (CA)[a]	OIW (F)[a]	OIW (RD)[a]	RIW (CC)[a]	RIW (RW)[a]	SIW (B)[a]	SIW (S)[a]
♯ of observations	870	739	1379	1466	4518	4498	351
♯ of subjects observed	6	2	4	7	12	10	3
♯ of day observations taken	3	3	3	6	6	9	2
	%	%	%	%	%	%	%
Trunk posture							
Neutral	75	87	66	70	52	56	70
Slight flexion (> 20°)	11	8	11	13	13	9	14
Severe flexion (> 45°)	11	4	18	15	28	22	15
Flexion and /or twist/bend[b]	3	1	5	2	7	13	1
Arms posture							
Elbows below shoulder	91	79	94	90	80	92	81
One elbow at/above shoulder	7	9	5	7	14	6	14
Two elbows at/above shoulder	2	12	1	3	6	2	5
Legs posture							
Stand (stable/even)	55	46	54	53	6	0	71
Stand (unstable/uneven)	17	33	8	20	70	54	3
Climb up/down	2	3	1	1	2	1	1
Walk/move	21	13	15	20	15	15	9
Sit	1	2	0	0	1	21	1
Squat	1	1	7	4	5	2	1
Kneel	3	2	15	2	1	7	14
MMH							
Lifting	3	4	2	3	4	2	0
Lowering	1	1	0	1	2	0	0
Pushing/pulling/dragging	16	1	2	6	11	6	7
Carry/hold—One hand	5	5	2	3	3	3	4
Carry/hold—Two hands	3	8	3	8	10	3	1
Jerking motion up/down	0	0	0	1	2	0	0
Carry position							
Elbows close to body	25	13	9	15	21	12	5
Elbows far from body	3	4	1	1	10	2	2
Weight							
Light (< 10 lb)	7	5	3	6	2	4	7
Moderate (10 lb–50 lb)	19	13	6	14	6	11	2
Heavy (> 50 lb)	2	0	1	3	19	1	3
Activity							
Assembling/disassembling	0	4	2	0	0	0	0
Positioning	13	9	10	21	36	8	7
Plumbing/measuring	0	3	4	0	0	2	0
Unreeling/tying/cutting wire	0	1	0	25	29	0	2
Screwing/bolting/riveting	3	2	9	1	3	15	11
Welding	0	2	0	1	0	11	0
Giving/receiving instructions	12	10	25	7	5	10	13

Table 3 (*continued*)

	Ironwork specialty (task)						
	MMRIW (CA)[a]	OIW (F)[a]	OIW (RD)[a]	RIW (CC)[a]	RIW (RW)[a]	SIW (B)[a]	SIW (S)[a]
Housekeeping/cleaning	2	3	1	2	0	0	2
Hammering	1	9	0	0	0	2	21
In between activities	46	32	24	30	25	31	28
Other activity not specified	23	26	24	13	2	21	16
Location of work							
Below knee height	8	0	20	5	19	19	0
Between knee and waist	10	2	3	9	4	14	4
Above waist height	11	40	13	45	12	14	48

[a] See Table 2 for task description.
[b] Combined frequencies for trunk postures. (i) twisted, (ii) side bend, and (iii) side bend or twist with flexion.

Table 4
Frequency of observed non-neutral postures, MMH, carry position, weights handled and work height for the four major CI specialties

	MMRIW (%)	OIW (%)	RIW (%)	SIW (%)
Posture				
Trunk	25	27	44	43
Arms	9	11	18	9
Legs[a]	45	48	82	95
MMH				
Lifting/lowering	4	3	5	3
Push/pull/drag	16	2	10	6
Carry or hold				
Carry Position	8	8	12	6
Elbows close to body	25	10	19	12
Elbows far from body	3	2	9	2
Weight handled				
Light (<10 lb)	7	4	3	4
Moderate (10 lb–50 lb)	19	8	11	10
Heavy (>50 lb)	2	0	15	1
Work height				
Below knees	8	13	15	17
Between knees and waist	10	3	5	13
Above waist	11	22	20	17

[a] Includes all leg postures except stand (stable/even).

specialties; however, the observed pushing/pulling/dragging MMH activity frequency was notably higher for MMRIW (16%) compared to the other CI specialties. Loads handled with elbows far from the body were observed approximately three time more frequently in RIW compared to the other CI specialties. Additionally, handling loads weighing more than 50 lb ($\geqslant$223 N) was notably higher for RIW (15%) compared to the other three CI specialties.

3.2. Trunk postures

For the trunk, the frequency of non-neutral postures ranged from a low of 13% for OIW(F) to a high of 48% for RIW(RW) (Fig. 1). RIW(RW) had the highest frequency of severe flexion (>45°), 28% of observations. For flexion with twist or side bending, SIW(B) had the highest frequency of 13% of time observed. Trunk postures differed significantly among tasks (chi-square on 30 d.o.f., $p<0.001$). Inspection of the contributions to the chi-squared statistic indicates that severe flexion was less likely for OIW(F) and more likely for RIW(RW) than one would expect to see under the assumption of independence of trunk and task.

3.3. Arm postures

For the arms, the majority of postures observed were neutral, i.e., both elbows below shoulder level (Fig. 2). Arm postures differed significantly among CI tasks (chi-square on 12 d.o.f., $p<0.001$). OIW(F), RIW(RW), and SIW(S) had the highest observed non-neutral arm posture frequencies of 21%, 20%, and 19%, respectively, while OIW(RD) the lowest observed frequency of 6%.

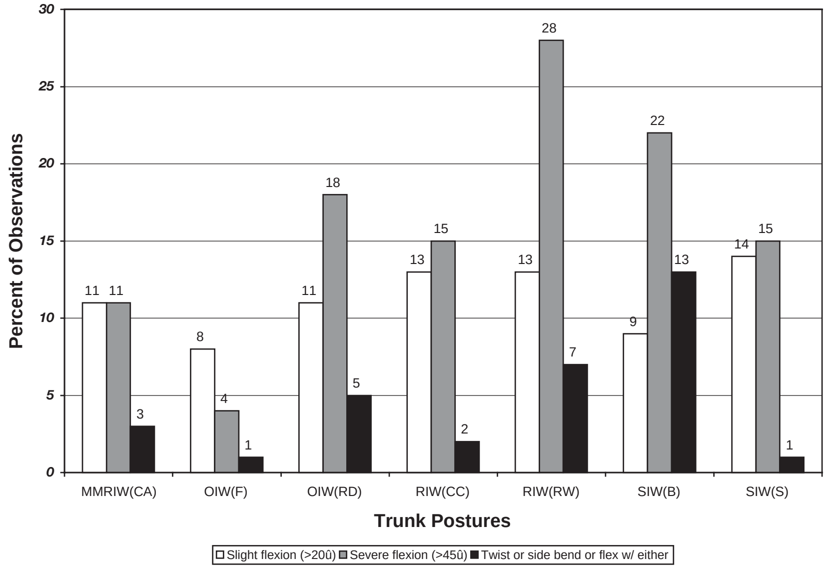

Fig. 1. Frequency of non-neutral trunk postures observed for seven CI tasks.

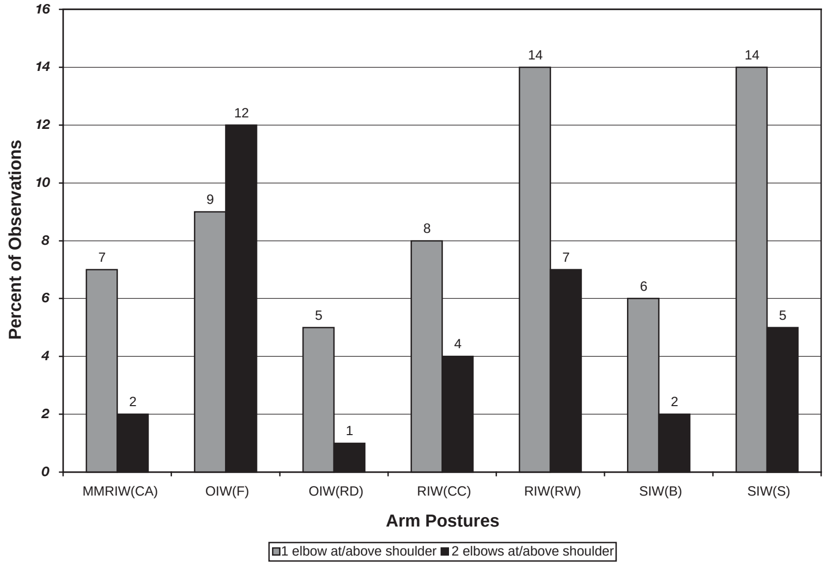

Fig. 2. Frequency of non-neutral arm postures observed for seven CI tasks.

For OIW(F), workers spent 12% of the work time with both elbows either at or above shoulder level.

3.4. Leg postures

Leg postures differed significantly among CI tasks (chi-square on 36 d.o.f, $p<0.001$). Standing on unstable/uneven surfaces was more likely for RIW(RW), whereas standing on stable/even surfaces was more likely for MMRIW(CA), RIW(CC), and OIW(RD). Standing on unstable or uneven surfaces varied from 3% for SIW(S) to 70% for RIW(RW) (Fig. 3). Walking or moving was also observed a fair amount of the time with

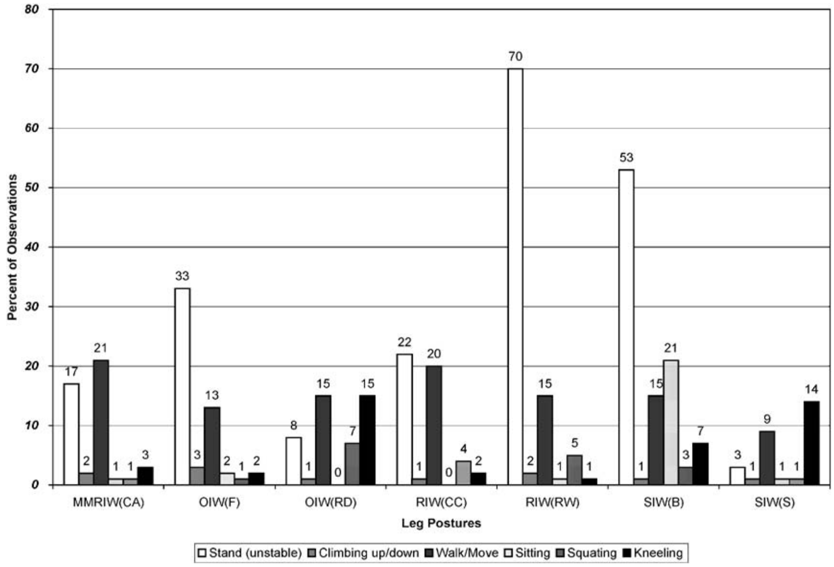

Fig. 3. Frequency of all leg postures except 'stand on stable/even ground' observed for seven CI tasks.

observed frequencies varying from 9% for SIW(S) to 21% for MMRIW(CA).

3.5. MMH activities

MMH activities (lifting, lowering, pushing, pulling, dragging, carrying, holding, forceful motions) were observed most frequently for RIW(RW) (32%) and MMRIW (CA) (28%). The percentage of time that ironworkers were observed doing MMH activities differed significantly among the seven tasks observed (chi-square on 36 d.o.f., $p<0.001$). The frequency with which loads were handled with elbows far from the body ranged from 1% for OIW(RD) to 10% for RIW(RW). Ironworkers handling loads weighing at least 10 lb (45 *N*) were observed 25% for RIW(RW) and 21% for MMRIW(CA) (Fig. 4). Handling of loads greater than 50 lb ($\geqslant 223\,N$) was observed 19% of the work time for RIW(RW) and only 1% of the work time for both OIW(RD) and SIW(B). Handling loads more than 50 lb was never observed for OIW(F).

The load handled or force exerted was found to be a significant predictor ($p<0.001$) of the position of the elbows with respect to the body, i.e., the carry position. When examined by task, loads handled/exertions made were found to be a very significant predictor of the carry position used for all seven CI tasks. In general, loads or exertions were handled or made with elbows close to the body (84%, 74%, and 73% for the $\leqslant 10$ lb ($\leqslant 45\,N$), 10^{+}–50 lb (45^{+}–$223\,N$), and 50 lb ($>223\,N$) ranges, respectively). Therefore, loads/exertions handled or made with the elbows far from the body were observed 16%, 26%, and 27% of the time, respectively. Examining the carry position used by task, loads/exertions exceeding 50 lb (223 *N*) with the elbows far from the body were observed 39%, 28%, and 4% of the time an MMH activity was performed for RIW(CC), RIW(RW), and SIW (B), respectively.

3.6. Work height

Working with the hands below knee height was observed approximately 20% of the time for OIW(RD), RIW(RW), and SIW(B). Working at or above waist height ranged from a low of 11% for MMRIW(CA) to highs of 45% and 48% for RIW(CC) and SIW(S) respectively. The working at or above waist height percentages also include the percentage of time the hands were above shoulder level. The frequency of time spent

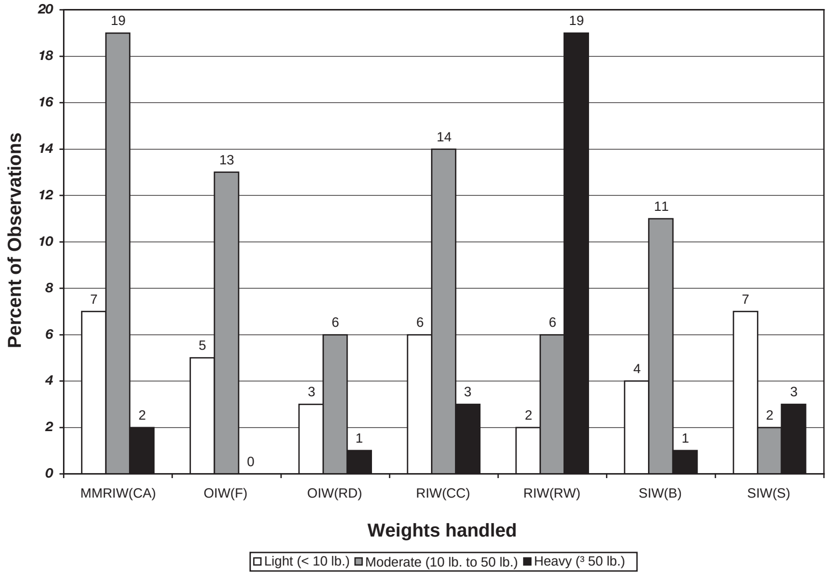

Fig. 4. Frequency of time handling various weights for seven CI tasks.

working below knee height in a severe trunk posture was found to vary from lows of 13% and 26% for RIW (CC) and SIW(S), respectively, to highs of 56%, 62%, and 68% for RIW(RW), SIW(B), and OIW(RD) respectively.

4. Discussion

4.1. Specific hazards associated with each CI task

4.1.1. Machinery moving/rigging ironwork (MMRIW)

For MMRIW(CA), several activities, most notably the activity ‘Positioning’, required a lot of pushing or pulling of very large and heavy crane segments into position in order to get the bolt openings to line up properly (16% of the work time observed) (Table 3). For an 8-h shift, this translates into approximately 1.3 h of significant whole-body exertional efforts. Several studies have identified overexertion as a potential work-related musculoskeletal disorder risk factor (see Bernard, 1997 for an extensive review). The anatomical sites found to be most at risk have been the back, legs, and shoulders.

4.1.2. Ornamental ironwork (OIW)

For OIW(F), workers were observed with one or both arms above shoulder level 21% of the work time. For this task, thin decorative aluminum strips had to be installed along the top one-third of the walls. The workers used a scaffold to reach the upper areas of the walls but its height was set such that the worker could reach the top of the work area without having to bend the trunk. Therefore, a neutral trunk posture was maintained; however, this was achieved as the expense of neutral arm postures since the worker now had to reach above shoulder height to reach the work area.

For OIW(RD), severe trunk flexion and/or twisting and side bending was observed 23% of the work time. The design of the revolving door observed in this study forced the workers to have to kneel or squat in order to assemble the base elements of the door. According to the foreman, however, other revolving door designs allow the base elements to be pre-assembled on a work bench and then simply attached to the door unit. Therefore, observations for the ergonomic exposures profiles for other revolving doors may yield risk exposures for the trunk and legs that are significantly lower than those found in this study.

4.1.3. Reinforcing ironwork (RIW)

For RIW(CC), this task involved the fabricating of rebar caisson cages which are stretched out coils of rebar supported along their lengths by straight rebar. Though the cages were built on adjustable stands, severe flexion ($<45°$) was observed 15% of the work time. Of the times severe flexion was observed, 50% of the time the activity being performed was tying rebar.

For RIW(RW), non-neutral trunk postures were observed 48% of the time. Therefore, it is quite likely that those engaged primarily in rebar ironwork are at a higher risk for work-related back disorders. When a non-neutral trunk posture was observed, the most likely activity performed was tying rebar (54%). With respect to leg postures, almost all RIW(RW) work was done while standing on uneven, semi-stable rebar networks. In addition to creating an increased strain on the ankle joints and calf muscles, walking on these unstable/uneven surfaces posed a constant trip and fall hazard.

Estimated frequency of load handling $>223\,N$ for RIW (15%) translates into over 1 h per shift. This is by no means an insignificant exposure; even rare load handling of this weight is considered potentially harmful. RIW(RW) involved the handling of loads equal to or greater than 50 lb ($\geqslant 223\,N$) for 19% of the work time observed. For an 8-h shift, this would translate into over 1.5 h of heavily lifting.

There is a potentially significant role for proper hand-tool design in reducing non-neutral hand/wrist postures such as flexion, extension, radial and ulnar deviation as a commonly seen in several RIW activities. For both RIW(RW) and RIW(CC), the activity 'Unreeling/tying/cutting wire' was observed 29% and 25% of the time. Due to the hand-powered pliers traditionally used, this activity exposes the ironwork to non-neutral hand/wrist postures which are usually coupled with repetitive, forceful exertions. Using ergonomically-designed wire-tying hand tools, Li (2002) found that muscular effort as well as the number of non-neutral postures were significantly reduced while subjective variables such as ease of use and exertion level went up.

Dababneh and Waters (2000) provide an extensive review of the five basic methods for rebar tying currently available. In comparing the ergonomic risk factors associated with each method along with other considerations such as each tool's range of usability, maintainability, and cost, they concluded that properly designed powered rebar tying tools may provide the best ergonomic solution to non-neutral hand/wrist postures and repetitive forceful hand motions.

Schneider and Susi (1994), in a review of ergonomic hazards associated with the construction of a four-story office building, listed three interventions that can be applied to eliminate or alleviate several ergonomic hazards commonly associated with RIW(RW): (i) better storage and layout of materials (e.g., storing rods at waist height), (ii) using a "tieing automat" (a metal extension device with a trigger handle at waist height) that allows the worker to tie rods from a standing height; and (iii) using prefabricated welded nets instead of individual rods, thus reducing the requirement for tying and MMH. Also, in RIW(RW), iron rods are often stored on the ground in bundles. Extracting rods from these piles required the ironwork to exert considerable muscular effort while in a severely flexed trunk posture. Sillanpää and colleagues (1998) tested a portable storage rack and cutting bench for reinforcement rods and found that it improved work posture and decreased the need for muscle strength.

Exposures within several RIW tasks varied depending on the specific activity being performed. For example, for RIW(CC), ironworkers were observed in non-neutral trunk postures only 28% of the work time when 'Positioning' but when the activity 'Unreeling/tying/cutting wire' was done, non-neutral trunk postures were observed 47% of the time. It is therefore important to characterize the ergonomic exposure profiles associated with each major activity within all CI tasks.

4.1.4. Structural ironwork (SIW)

For SIW(B), non-neutral trunk postures were high (44%), with severe flexion ($>45°$) and/or twisting/side bending being observed 35% of the work time. Much of this task (54%) was done at heights of 20–50 ft above the ground or floor level on narrow beams where good stability and keen attention by the worker to feet location and movements were imperative to avoid slipping and falling.

For SIW(S), non-neutral trunk postures were observed 30% of the time. Most of the work was done standing on a stable/even surface (71%), however, kneeling and squatting was observed 15% of the time. Therefore, it is quite likely that those engaged primarily in structural ironwork for buildings are at a higher risk for work-related back disorders.

4.2. Summary of findings

In this study, ironworkers engaged in seven specific CI tasks were found to experience multiple ergonomic stresses. The characteristics of the ergonomic exposure profiles associated with each task observed significantly differed among the seven CI tasks. Both task and activity performed were found to be major predictors of the percent of work time spent in various postures, MMH activities, and working height. These results illustrate the need to use a task-based exposure assessment strategy in order to properly quantify the levels of ergonomic risk experienced by the workers.

It is very important to characterize the ergonomic exposure profiles associated with each major activity within all CI tasks since exposures within any given CI task were found to vary depending on the specific activity being performed.

The most obvious ergonomic hazards identified for all CI tasks were non-neutral postures of the trunk, arms, and legs. For RIW(RW) and SIW(B), trunk flexion, twisting, and side bending were seen on 35% of the work sampling observations. In an industrial setting, non-neutral trunk frequencies of 10% were found to be significantly associated with a marked increase of risk for work-related back disorders (Punnett and Paquet, 1996). Therefore, it is quite likely that those engaged primarily in CI tasks as rebar work and structural ironwork for buildings are at a higher risk for work-related back disorders. Results from other studies have already indicated an elevated prevalence of low back disorders among rebar ironworkers (Riihimaki et al., 1990; Riihimaki, 1985; Nummi, et al., 1978; Saari and Wickstrom, 1978; Wickstrom, 1978; Lindstrom et al., 1974).

Although loads handled during MMH activities were usually less than 50 lb ($<223\,N$), ironworkers handling loads exceeding 100 lb ($>446\,N$) were periodically observed, particularly for RIW(RW) and SIW(B) ironwork. Such peak lift exposures of this magnitude far exceed NIOSH's recommended weight limit and occur under conditions that are usually far from ideal (Waters et al., 1993). MMH exposures can therefore be considered to be a major risk factor in ironwork and a key etiologic factor in an increase of ironworker's risk for back injury.

For a major portion of the work time observed, the workers were in between activities. This category was observed approximately 25–30% of the work time. This is fairly typical of most construction work where the work pace and activity content is highly variable and can dramatically vary from day to day. Typical of all CI tasks observed in this study were periods of intense activity broken up by long periods of relative inactivity. Even when the ironworker was actively engaged in a specific activity, because the work was not machine paced, s/he had the opportunity to take many micro-breaks as desired. Therefore, CI workers are usually able to recuperate, if needed, and operate at a pace that matches their capabilities.

Care should also be taken in generalizing the results of this study to all types of CI tasks. For RIW and SIW, the tasks chosen for observation are frequently performed by ironworkers who specialize in these CI specialties. Since rebar work (for RIW) and building erection (for SIW) constitute the major tasks performed by ironworkers engaged in these specialties, respectively, the ergonomic exposure profiles found in this study for these two CI specialties are very likely to be representative of these CI specialties. For OIW and MMRIW, the tasks observed were very specific and hence are less frequently performed by ironworkers engaged in these CI specialties. By nature, OIW is the most variable CI specialty and so the observed tasks ('Revolving door installation' and 'Finishing') may only be representative of these specific tasks and not OIW as a whole.

Similarly, the tasks associated with MMRIW tend to be very specific to each project and so the ergonomic exposure profile reported in this study for MMRIW should not be generalized to being representative of this specialty as a whole.

Other factors may also affect the generalizability of these results. As illustrated, each CI task usually has a unique exposure profile. Additionally, the observed frequencies obtained in this study would have been affected by the conditions prevailing at the time of data collection. For example, MMRIW(CA) data were collected in the winter, mostly on days when snow was falling heavily, whereas RIW(RW) and RIW(CC) data were collected during the summer months. Furthermore, the type of construction site, the contractor selected, and type of workers observed (unionized versus non-unionized) may materially affect the ergonomic profiles generated. The implications of this are that in addition to the type of task and activity being performed, external factors such as the external working environment and work organizational factors may significantly modify the exposure profile. Future studies are need to determine the extent and degree such factors have on modifying exposures.

Although there are clear differences in the exposure profiles at the task level, clear distinctions can still be seen at the CI specialty level. For example, non-neutral trunk postures are approximately 17% higher for RIW and SIW compared to OIW and MMRIW (Table 4). Similarly, non-neutral leg postures (i.e., all leg postures except stand on stable/even surface) are approximately 43% higher for SIW and RIW compared to MMRIW and SIW. With respect to non-neutral arm postures, non-neutral arm postures are approximately twice as high in RIW compared to all other CI specialties. Therefore, in terms of risk to specific parts of the anatomy, these data suggest that those who specialize in RIW and SIW will have a greater risk of trunk and leg musculoskeletal problems; and for the shoulders, RIW would pose the highest risk. When the frequency of MMH activities, location of elbows when carrying/handling loads and the weight of loads handled are considered, it is clear that RIW again poses the greatest overall stress on the musculoskeletal system and hence highest risk for adverse upper extremity and lower back MSD health problems.

4.3. Strengths and limitations of PATH

Systematic bias in PATH data collection is unlikely because exposure data were collected on multiple workers over multiple days across the entire work shift. The coding protocol did not depend on what a worker was doing and so avoided overestimation of frequencies of "interesting" exposures. With respect to random exposure misclassification, inter-observer agreement was at least 80% for all codes and checked periodically throughout this study, and so, exposure misclassification is unlikely to have been a serious source of error.

5. Conclusions

This study, as well as others (e.g., Lindstrom et al., 1974; Nummi et al., 1978; Saari and Wickstrom, 1978; Wickstrom, 1978; Riihimaki et al., 1990; Riihimaki, 1985; Buchholz et al., 2003), clearly identify CI as a construction trade wherein exposures to ergonomic risk factors such as awkward postures, heavy lifting, and forceful exertions are significant. As is typically true of most trades, however, the ergonomic risk profiles can and do vary depending on the specific specialty, task, and activity being performed.

In CI, there are four main specialties—MMRIW, OIW, RIW, and SIW—each with multiple, unique tasks and activities. There therefore exists a need for studies which clearly quantify and define the shape of these profiles by CI specialty, tasks, and activities. This study is a first step towards establishing a task-based database on ergonomic exposures common to CI. Once task-specific ergonomic exposure profiles are determined for each CI specialty, then their association with adverse musculoskeletal health outcomes can be determined in future epidemiologic studies. Furthermore, researchers can then be better able to propose and develop preventive ergonomic interventions that are targeted on the most hazardous tasks and activities of each CI specialty.

The results of this research can be used in developing improved tools and work methods. For example, changes in the tools and work methods used in RIW(RW) and SIW(B) have the potential to reduce the frequency of non-neutral trunk and arm postures for these two CI tasks (Schneider, 1994; Li, 2002). Tools that reduce the amount of below knee level and above shoulder level work can be designed and used for these tasks (Sillanpää et al., 1999). Additionally, materials engineering and layout strategies can be implemented that minimize the maximum weight lifted or MMH activity required.

The effectiveness of any changes made in work methods or tools used can be analyzed using the analytic method employed in this study. Employing such a specialty-task-activity-based, work-sampling based technique which associates specific work postures with specific work activities will enable researchers and others to develop work interventions that have been proven to actually decrease exposures to adverse ergonomic risk factors.

Acknowledgements

This work was performed when the corresponding author was at the University of Massachusetts Lowell as a Research Assistant on the Construction Occupational Health Project. This project was funded by the National Institute for Occupational Safety and Health (NIOSH) through the Center to Protect Workers' Rights (CPWR) (Grant U02/CCU312014). We would like to thank members from the COPH that participated in this study specifically Susan Moir, Ted DesMarais, Brian Murray, Jenny Ro, Min-Young Song, and Scott Fulmer.

References

Bernard, B.P. (Ed.), 1997. Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back, Second Printing. National Institute for Occupational Safety and Health (NIOSH) US Department of Health and Human Services, Centers for Disease Control Safety and Health, Publication No. 97-141

Buchholz, B., Paquet, V., Punnett, L., Lee, D., Moir, S., 1996. PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Applied Ergonomics 27, 177–187.

Buchholz, B., Paquet, V., Wellman, H., Forde, M., 2003. Quantification of ergonomic hazards for ironworkers performing concrete reinforcement tasks during heavy highway construction. American Industrial Hygiene Association Journal 64, 243–250.

Bureau of Labor Statistics, BLS, 2001, http://stats.bls.gov/iif/oshwc/osh/os/osnr0016.pdf

Center to Protect Workers' Rights, CPWR, 1994. Work-Related Musculoskeletal Disorders: A Construction Biography. CPWR, Washington, DC.

Center to Protect Workers' Rights, CPWR, 1996. Construction Safety and Health Research: Five Years of Progress and Proposals for the Future Report of the CPWR-NIOSH Program Planning Conference "Joint Strategies to Advance Research in the Construction Industry" Cincinnati, OH, April 1–2.

Cook, T., Rosecrance, J., Zimmermann, C., 1996. The University of Iowa Construction Survey. Biomechanics and Ergonomics Facility, University of Iowa, Iowa City, IA.

Dababneh, A.J., Waters, T.R., 2000. Ergonomics of rebar tying. Applied Occupational and Environmental Hygiene 15 (10), 721–727.

Forde, M.S., 2002a. Ergonomic job analysis: structural ironwork. Technical Report T-59, Construction Occupational Health Program, Department of Work Environment. University of Massachusetts Lowell, Lowell, MA.

Forde, M.S., 2002b. Reinforcing ironwork: PATH (Posture, Activity, Tools, Handling) analysis. Technical Report T-61, Construction Occupational Health Program, Department of Work Environment, University of Massachusetts Lowell, Lowell, MA.

Guo, H.-R., Tanaka, S., Cameron, L.L., Seligmn, P., Behrens, J., Wild, D., Putz-Anderson, V., 1995. Back pain among workers in the United States: National estimates and workers at high risk. American Journal of Industrial Medicine 28, 591–592.

Hart, D., Link, J., 1991. Ergonomic Job Analysis: Iron Worker, Center to Protect WORKERS rights. New York, Washington, DC.

Holstrom, E., Lindell, J., Moritz, U., 1993. Healthy lower backs in the construction industry in Sweden. Work and Stress 7, 259–271.

Kisner, S., Fosbroke, D., 1994. Injury hazards in the construction industry. Journal Occupational Medicine 36, 137–143.

Kivi, P., Mattila, M., 1991. Analysis and improvement of work postures in the building industry: application of the computerized OWAS method. Applied Ergonomics 22, 4348.

Li, K.W., 2002. Ergonomic design and evaluation of wire-tying hand tools. International Journal of Industrial Ergonomics 30 (3), 149–161.

Lindstrom, K., Wickstrom, G., Riihimaki, H., Nummi, J., Wiikeri, M., Saari, J., Launis, M., 1974. Reinforced concrete workers. Part 1. Working Conditions and State of Health—A Questionnaire; Part 2. Clinical Examination; Part 3. Ergonomic Analysis. Institute of Occupational Health, Helsinki, Finland, 3 Booklets, 81, 134, 141pp.

Nummi, J., Jarvinen, T., Stambej, U., Wickstrom, G., 1978. Diminished dynamic performance capacity of back and abdominal muscles in concrete reinforcement workers. Scandinavian Journal of Work, Environment and Health 4 (Suppl. 1), 39–46.

Nurminen, M., 1997. Reanalysis of the occurrence of back pain among construction workers: modeling for the interdependent effects of heavy physical work, earlier back accidents, and aging. Occupational and Environmental Medicine 54, 807–811.

Pan, C.S., Gardner, L.I., Landsittel, D.P., Hendricks, S.A., Chiou, S.S., Punnett, L., 1999. Ergonomic exposure assessment: an application of the PATH systematic observation method to retail workers. International Journal of Occupational and Environmental Health 5, 79–87.

Paquet, V., 1998. The assessment of ergonomic exposures in construction work. Sc.D. Dissertation. University of Massachusetts Lowell, Lowell, MA.

Paquet, V., Buchholz, B., Woskie, S., Punnett, L., 1996. Distributions of the percent of time highway construction workers spend in awkward trunk postures: implications for measurement strategies and analysis of non-repetitive work. Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting, Philadelphia, PA.

Punnett, L., Paquet V., 1996. Ergonomic exposures to carpenters and carpentry laborers in tunnel construction. In: Mital, A., et al. (Ed.), Advances in Occupational Ergonomics and Safety I, Proceedings of the XIth International Occupational Ergonomics and Safety Conference, IOS Press, Amsterdam.

Riihimaki, H., 1985. Back pain and heavy physical work: a comparative study of concrete reinforcement workers and maintenance house painters. British Journal of Industrial Medicine 42, 226–232.

Riihimaki, H., Mattsson, T., Zitting, A., Wickstrom, G., Hanninen, K., Waris, P., 1990. Radiographically detectable degenerative changes of the lumbar spine among concrete reinforcement workers and house painters. Spine 15, 114–119.

Riihimaki, H., Wickstrom, G., Hanninen, K., Luopajarvi, T., 1989. Predictors of sciatic pain among concrete reinforcement workers and house painters—a five-year follow-up. Scandinavian Journal of Work, Environment and Health 15, 415–423.

Saari, J., Wickstrom, G., 1978. Load on back in concrete reinforcement work. Scandinavian Journal of Work, Environment and Health 4 (Suppl. 1), 13–19.

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

Schneider, S., Susi, P., 1994. Ergonomics and construction: a review of potential hazards in new construction. American Industrial Hygiene Association. Journal 55, 635–649.

Sillanpää, J., Lappalainen, J., Kaukiainen, A., Viljanen, M., Laippala, P., 1999. Decreasing the physical workload of construction work with the use of four auxiliary handling devices. International Journal of Industrial Ergonomics 24, 211–222.

Stata Corporation, 1999. Stata Version 6. Stata Corporation, College Station, TX.

Waters, T., Putz-Anderson, V., Garg, A., Fine, L., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36, 749–776.

Wickstrom, G., 1978. Symptoms and signs of degenerative back disease in concrete reinforcement workers. Scandinavian Journal of Work, Environment and Health 4 (Suppl. 1), 54–58.