Hand Lacerations and Job Design Characteristics in Line-Paced Assembly

Jennifer L. Bell, PhD
Leslie A. MacDonald, ScD

This study investigated risk factors for laceration injuries among workers employed in line-paced manufacturing assembly operations. Most lacerations (76% of 576) occurred on the hands and fingers (grouped as "hand" lacerations). On average, 37% of surveyed workers reported at least one laceration to the hand in the preceding year, resulting in an overall hand laceration rate of 83 per 100 workers per year. An inverse relationship was found between level of job routinization and hand lacerations, with progressively higher rates of hand lacerations occurring among workers assigned to less routine (more variable) work patterns. Fabricated metal parts handling and job variability may be related to increased risk of hand lacerations in line-paced work environments where personal protective equipment is the primary strategy to control exposure to sharp objects. (J Occup Environ Med. *2003;45:848–856*)

Lacerations ranging from minor injuries requiring little more than a bandage to severe injuries damaging tendons or nerves are one of the most commonly reported injuries incurred by workers while on the job. When examining work-related hospital emergency department and medical center visits, laceration injuries consistently have ranked in the top three most numerous injuries.[1–6] Lacerations have been cited repeatedly as an important source of injury in a wide variety of occupations and industries.[7–12]

Work-related laceration injuries most commonly affect the hands and fingers, often resulting in days lost from work and considerable employer expense.[3,10,12–14] Lost work time associated with a laceration can be protracted because hand wounds can impede manual task performance and there often is no alternative work that can be assigned during recovery.[3] Laceration injuries also increase workers' susceptibility to injury after chemical exposure because damage to the dermal barrier permits increased percutaneous absorption.[15,16]

Although the frequency, severity, and cost of laceration injuries have been fairly well documented, there conversely is a lack of studies describing detailed risk factors for lacerations. Lacerations occurring in association with the use of manual cutting tools (eg, knives and box cutters), powered tools, and sharp object handling have been documented, but this information generally has only been descriptive.[3,9,10] However, two quantitative studies

From the Division of Safety Research, Analysis and Field Evaluations Branch (Dr Bell) and Division of Surveillance, Hazard Evaluation, and Field Studies, Industrywide Studies Branch (Dr MacDonald), National Institute for Occupational Safety and Health (NIOSH), Morgantown, West Virginia and Cincinnati, Ohio, respectively.

Address correspondence to: Jennifer L. Bell, PhD, Research Epidemiologist, Analysis and Field Evaluations Branch, Division of Safety Research, National Institute for Occupational Safety and Health, 1095 Willowdale Road MS-1811, Morgantown, WV 26505-2888; e-mail address: JBELL@CDC.GOV.

DOI: 10.1097/01.jom.0000083032.56116.88

were able to identify risk factors for occupational hand injuries.[17,18] Using a case–control design, Hertz and Emmett[17] found that performing a task that was not a usual job requirement, using defective materials, the presence of cardiovascular disease, extended sleep patterns, and youth (age less than 25 years) were associated with hand lacerations. Sorock et al[18] used case-crossover methodology to examine transient risk factors and found risk of injury to be elevated when equipment or materials performed differently while performing an unusual work method or task, while being distracted, and while being rushed. Although these studies dealt with a variety of hand injury types, both of these studies identified lacerations as the most common form of hand injury.

In this study, three retrospective annual surveys were conducted to investigate the incidence of laceration injury events among workers employed in line-paced manufacturing assembly operations within an appliance manufacturing plant. It was hypothesized that modifiable occupational factors, such as the handling of sharp objects (fabricated metal parts) and job variability, would be positively associated with hand laceration rates, after adjustment for nonmodifiable factors (eg, age, job tenure). The specific goal of this study was to identify occupational risk factors for hand laceration injuries. The implications of our findings for the prevention of occupational hand laceration injuries is discussed.

Methods

Study Population

All production workers employed full-time in two washing machine assembly operations during three survey periods (1995, 1997, and 1999) were eligible for enrollment in the study. On both assembly lines, workers were assigned to direct production (fabrication and assembly) or support functions (eg, in-line repair, floaters, utility workers). For direct production assembly workers, a conveyor transported washing machine units between workstations at a fixed interval and work was hand intensive and highly routinized. The pace of workers in support functions was generally not fixed and the work tasks were more variable. On the assembly line where traditional top-load washing units were produced, cycle times for direct production functions were 22 seconds at the start of the study (1995) and were found to be shorter during each successive survey (17 and 14 seconds, respectively), job rotation was fairly uncommon (no more than 25% of the assembly jobs), and job rotation was voluntary for all but a few jobs.

The second washer assembly line, which was newly designed for the production of a new front-load washer, was not yet fully operational at the time of the initial survey in 1995. Job functions among the small team of production workers assigned to the new line in 1995 had no fixed work cycle. Tasks at that time involved implementing coordinated process engineering activities such as parts ordering, tolerance checks, and the installation and configuration of workstations and tooling. With each subsequent survey, job functions on the new line were increasingly routinized and cycle times were successively reduced to ≥33 seconds in 1997 and ≥28 seconds in 1999 (cycle times between work cells on the new line varied slightly). In contrast to the voluntary job rotation on the traditional line, production tasks on the new line were organized into work cells and a mandatory hourly rotation between jobs within each cell was implemented through department policy.

Data Collection Procedures

All participating workers completed a self-administered questionnaire during normal work hours (time was set aside for the survey by plant management) for each of the three survey periods. The same questions were presented during each survey period except where otherwise noted below. Information about individual factors were obtained by questionnaire. These factors included gender, age (<25 years, ≥25 to 49 years, ≥50 years), height (<65 inches, ≥65 inches to 71 inches, ≥ 71 inches), body mass index (<30, ≥30), smoking status (current nonsmoker, current smoker), hand dominance (left, right, neither), and upper limb musculoskeletal case status. Case status was designated as positive if symptoms (pain, aching, stiffness, burning, numbness, or tingling) in the neck, shoulder, elbow, or hand/wrist were reported within the past year that lasted more than 1 week or occurred at least once per month in the past year.[19]

A four-category "job routinization" variable was created from a combination of job title data and data obtained from interviews with key informants to distinguish the job scope and content of distinct workgroups. Exposure data from direct observational assessments of all workers assigned to direct production were used to supplement these data for determinations of job rotation status and whether metal parts were handled. The four categories of routinization (from high routinization to low) were defined as follows: 1) in-line inspection tasks, 2) single "mono" short-cycle assembly tasks, 3) multiple short-cycle assembly tasks (ie, job rotation), and 4) a "non-routine" group comprised of in-line product repair workers, "floaters" who fill in for assembly workers who are absent or need to leave the line, utility workers who provide direct support of line operations, and technicians who set-up and troubleshoot production equipment. The first two groups (in-line inspection and mono tasks) were similar in their level of routinization but are distinguished by the amount of metal parts handling, with in-line inspection workers generally not required to handle metal parts.

Work-related factors, such as work shift (first, second, or third) and time in current job (time in current job ≤3 months, >3 months to 1 year, > 1 year), were obtained by questionnaire. For the small proportion of participants who had missing values for work shift and/or job tenure, data for these variables were obtained by company records. Measures of physical job stressors were selected primarily from checklists developed as part of the Occupational Safety and Health Administration's proposed 1995 Ergonomic Protection Standard.[20] These physical demand measures included time spent in awkward body postures of the upper limbs, work pace conditions, manual impact force (eg, using the hand as a hammer), and tool use. Pictures were included as visual guides to aid worker judgments in selecting posture categories. In addition, a rating of perceived exertion was obtained, using a modified five-point response scale as described by Varghese et al.[21]

Work-related laceration outcomes were identified from participants' questionnaire responses. Workers were asked "in the past year, have you received any cuts or lacerations anywhere on your body while at the [name of company] plant?" Those who responded "yes" were then asked to report "yes or no" for all body locations where a laceration injury or injuries occurred ("face, head or neck," "shoulder or arm," "hand or wrist," "fingers or thumbs," "back, chest, stomach," "legs, feet, hip area"). For each body location in which workers experienced a laceration, they were asked to then report "yes or no" if the injury occurred on their current job. Workers were not asked to report on the severity of the injury. For those participants reporting laceration outcomes during the third survey period (1999), additional information was collected on the injury source (ie, type of equipment, tooling or materials). Participants of the 1999 survey were also asked about their use of personal protective equipment (PPE). Information related to PPE use was sought for duration of use per day, body area protected and, if applicable, reasons for not using PPE.

Data Analysis

Using the procedure of Schoemaker et al,[22] laceration rates were calculated using the number of hand laceration injury incidents incurred at the study site while working in the current job (up to 1 year) as the numerator, whereas time employed in the current job (in days) defined the value for the denominator (up to 1 year). Rates were expressed as rate of laceration incidents as opposed to rate of lacerated persons.[23] Time in current job was defined according to the date each worker completed the study questionnaire in relation to the date each worker reported being assigned to their current job. This procedure allowed rates to be computed despite missing information on the number of hours worked by each employee each year. Rates were multiplied by 100 and expressed as number of laceration incidents per 100 worker-years.

The data were treated cross-sectionally, with associations between lacerations, exposures and covariates examined within each survey period. Poisson regression was used to compute crude rate ratios (cRR), adjusted rate ratios (aRR) and 95% confidence intervals (CI) for the assessment of the relationship between laceration rates and predictor variables.[24–26] Because of repeat participation by some study subjects, generalized estimating equations with an autoregressive correlation structure were used to control for within-worker correlation.[27,28] Generalized estimating equation adjustment was not used for the subset of measures only included in the 1999 survey. Covariation was assessed among key variables using chi-square tests.

Results

There were 769 questionnaires completed from 497 employees during three survey periods (1995, 1997, 1999). Because of changes in the number of work shifts and per shift production volume between each survey, the number of eligible production workers varied from a low of 253 (1997) to a high of 461 (1999) and participation rates ranged from 71% (1999) to 90% (1997). Twenty-six questionnaires were omitted because they had missing data for laceration outcome or time employed in the current job, leaving 743 questionnaires available for analysis. Of the 743 questionnaires, 214 (29%) were completed in 1995, 219 (29%) in 1997, and 310 (42%) were completed in 1999. Fifteen percent of the participants completed all three questionnaires, whereas 20% completed two, and 65% completed one questionnaire.

The average age of the study participants was 39 years (range, 18–67 years). Although the average time employed in the current job assignment was 2 years (range, 0.01–30 years), the total time employed at the appliance plant averaged 10 years (range, 0.23–41 years). Half of the participants were female.

There was a total of 576 lacerations (anywhere on the body) reported during the three survey periods (Table 1). Workers could have a value of zero for laceration incidents if they checked none of the body locations and potentially a value of six if they checked all of the body locations. For hand lacerations, workers could have a value of zero, one (if they checked either hand or finger) or two (if they checked both hand and finger).

Most lacerations (76%) occurred on the fingers (44%) and hands (32%). The proportion of lacerations at other body sites ranged from 2% for the head to 13% for the arms. Lacerations at the different body parts were correlated with each other. People who reported a lacera-

TABLE 1
Summary Information for Study Population by Each Survey Period

	July 1995	March 1997	August 1999
Overall number of workers available for enrollment	272	253	461
Number of participants	220	222	327
Participation rate (before 26 questionnaires omitted)	81%	90%	71%
Traditional line cycle time	22 s	17 s	14 s
New Line cycle time	Not fixed[1]	≥33 s	≥28 s
Total no. lacerations (total body)	147	128	301
Total no. hand lacerations	109	105	223
% (no.) participants with at least one hand laceration	31% (67)	30% (66)	46% (144)
% (no.) participants with >1 hand lacerations (ie, reporting both a hand and a finger laceration)	20% (42)	18% (39)	25% (79)
Number of worker years	153.3	160.1	207.6
Hand laceration rate per 100 workers per year	71.1	65.6	105.9

* Because of start-up operations, cycle times were not established at the time of the initial survey. Cycle times between work cells on the new line varied slightly.

tion to the finger (the most common location) were significantly more likely to also report a laceration during the same survey period to all other body parts. The hand (chi-square = 320.8, $P < 0.0001$), head (Fisher exact test, $P = 0.0183$), back (Fisher exact test, $P < 0.0030$), arm (chi-square = 94.19, $P < 0.0001$), and leg (chi-square = 45.13, $P < 0.0001$). Because hand and finger (hereafter both grouped as "hand") lacerations were so prevalent, all subsequent analyses focused on injury to this body area. On average, 37% of surveyed workers reported at least one hand laceration (ie, cut to the hand, finger, or both) during a survey period. The overall rate of hand lacerations was 83 per 100 worker-years.

Participants from the 1999 survey reported the following sources of hand lacerations: 76% were related to stamped metal parts (appliance cabinet, panel etc.), 72% related to large assembly parts (console, base, tub), 50% related to small assembly parts (wires, screws, clips, springs, fill hose etc.), 14% related to the workstation, 7% related to hand tools (powered and non-powered), and 5% related to machinery. One quarter (26%) checked the "other" category (utility knife, metal packing bands, cardboard box etc.). Because these numbers include multiple lacerations per subject and because the categories are not mutually exclusive, they do not sum to 100%.

A majority (68%) of the participants in 1999 reported wearing PPE at least some of the time to protect against lacerations. Of the workers who wore PPE at least some of the time, the majority (80%) reported wearing gloves, 45% reported wearing finger tape, 10% reported wearing arm guards, 8% reported wearing an apron, and 4% reported wearing other PPE. Aside from those workers who reported that they felt that PPE was not necessary for their job, reasons stated among those who did not wear PPE were as follows: PPE got in the way of work performance (69%), it was uncomfortable because factory temperatures were too hot (19%), poor fit (14%), PPE was not readily available (2%), and "other" (14%); workers' could provide multiple answers so these results do not sum to 100%.

In univariate analyses, an inverse relationship was found between age and hand laceration rates. Compared with those 50 years and older, those aged 25 to 49 years and those less than 25 years had higher hand laceration rates (cRR = 1.58, 95% CI, 1.18–2.12 and cRR = 4.08, 95% CI, 2.72–6.10, respectively). Smokers were found to have higher hand laceration rates than nonsmokers (cRR = 1.45, 95% CI, 1.14–1.85). Workers with upper-limb musculoskeletal pain were found to have higher hand laceration rates than workers who did not report any pain (cRR = 2.23, 95% CI, 1.49–3.34). This association was insensitive to the severity of musculoskeletal symptom status because those who were symptomatic but did not meet the frequency and duration criteria for "case status" had a similar risk profile (cRR = 2.31, 95% CI, 1.59–3.40). No significant associations with hand lacerations were found for sex, height, body mass index, or right or left handedness.

A strong inverse relationship was found between job tenure and hand laceration rate in univariate analyses. Compared with workers employed in the current job more than 1 year, workers employed more than 3 months up to 1 year and those workers employed 3 months or less had significantly higher hand laceration rates (cRR = 2.01, 95% CI, 1.59–2.54 and cRR = 9.44, 95% CI, 7.10–12.59, respectively). Because job tenure was highly associated with laceration rates and because of its strong correlation with individual factors also associated with laceration rate (age, chi-square = 54.01, $P < 0.0001$ and smoking status, chi-square = 12.10, $P = 0.0023$), it was used as a covariate in multivariate modeling to assess the effect of other work-related variables on hand laceration rates.

TABLE 2
Rate ratios (with Lower and Upper 95% Confidence Limits) for Hand Lacerations Adjusted for Job Tenure and the Proportion of Workers Reporting Continuous Personal Protective Equipment (PPE) Use by Routinization Level

Routinization Level	n*	aRR	LCL	UCL	Continuous PPE (%) (>4 h per day)†
Inspection	87	1.00	Reference		38
Mono task	242	**1.80**	1.13	2.85	42
Fixed job rotation	219	**2.03**	1.28	3.19	27
Non routine	190	**2.12**	1.33	3.39	14

Bold face indicates $P < 0.05$.
* Surveys ($n = 743$) were included in the laceration analysis but not all people responded to every question; therefore, sample sizes do not always sum to 743.
† PPE use percentiles apply only to subjects who participated in the last survey, $n = 310$.

Multivariate Modeling

There was no significant difference in laceration rates between the two washer assembly lines (aRR = 1.16, 95% CI, 0.91– 1.48) or between first and second/third shift workers (aRR = 1.22, 95% CI, 0.98– 1.52), after adjustment for job tenure. Compared with the 1995 survey, the laceration rate was not different in 1997 (aRR = 0.97, 95% CI, 0.74– 1.27), but it was higher in 1999 (aRR = 1.37, 95% CI, 1.07– 1.75).

Compared with workers in line-paced inspection tasks, line-paced assembly workers in mono-task jobs who handled more fabricated metal parts had an 80% higher risk of hand lacerations after adjustment for job tenure. Moreover, an inverse relationship was found between level of job routinization and hand lacerations, where a progressively higher rate of hand lacerations occurred among workers assigned to less routine work patterns such as multi-task job rotation and direct production support functions (eg, floater, utility worker, reject repair; Table 2). When level of job routinization was examined in relation with PPE use, continuous PPE use during the entire workday was less common among workers who rotated (27%) or who were employed in less routine work patterns (14%); these workers reported more *occasional* PPE use during the workday (chi-square = 33.80, $P < 0.0001$).

Examination of the associations between workers' exposure to physical job stressors and hand laceration rates showed a general trend that those exposed for part of the workday were at higher risk than those reporting no exposure to specific physical stressors or those exposed the entire workday (Table 3). This pattern of increased risk among those with occasional daily exposure to physical stressors was shown for tool use, awkward body postures, forceful grasping, and PPE use. More global indices of physical job stress related to work pace demands (difficulty maintaining work pace for 8 hours per day) and rating of perceived exertion (overall physical effort level demanded by your job) showed progressively higher rates of hand lacerations with higher stressor levels (Table 3).

Discussion

In this study of production workers employed full-time within a household appliance manufacturing facility, the rate of laceration injuries was examined and risk factors for hand lacerations were identified. Of the total number of lacerations reported ($n = 576$) over the three survey periods, the vast majority (76%) occurred on the hands and fingers. On average, 37% of the study participants reported at least one hand laceration during each survey period. Compared to workers assigned to routine in-line inspection tasks, all other workers in direct production and support functions were at greater risk of hand lacerations. Routine (mono) task assembly workers had an 80% increased risk of hand lacerations, compared to workers assigned to in-line inspection tasks where metal parts handling is generally not required. The increased risk was 2-fold for assembly workers who rotated, generally on an hourly basis, among multiple short cycle job tasks, while risk was greater than 2-fold for workers assigned to more variable work patterns. Further examination showed that workers who rotated or who were employed in less routine work patterns were less likely to consistently use personal protective equipment throughout the workday.

Consistent with the result that more variable work patterns (eg, job rotation or non-routine job functions) were associated with higher laceration rates, examination of associations with physical job stressors showed that laceration rates were higher among those with occasional daily exposure to conditions such as tool use and awkward body postures while working, compared with those who were not exposed or who were exposed the entire workday. The data also showed that difficulty maintaining work pace and higher exertional demands on the job were associated with progressively higher increased risk for hand lacerations among all workers.

TABLE 3
Rate Ratios (With Lower and Upper 95% Confidence Limits) of Hand Lacerations for Physical Work Load Characteristics, Adjusted for Job Tenure

Independent Variables	*n**	aRR†	LCL	UCL
Time spent using an impact tool (eg, hammer)				
Never	380	1.00	Reference	
<2 h/day	181	**1.48**	1.16	1.90
2–4 h/day	41	**1.75**	1.23	2.50
>4 h/day	88	1.29	0.91	1.84
Time spent operating a power tool				
Never	291	1.00	Reference	
<2 h/day	74	1.31	0.94	1.82
2–4 h/day	115	**1.39**	1.02	1.89
>4 h/day	230	1.22	0.94	1.59
Time spent using the hand (palm) as a hammer				
Never	429	1.00	Reference	
<2 h/day	152	**1.96**	1.56	2.46
2–4 h/day	43	0.99	0.61	1.59
>4 h/day	55	1.19	0.81	1.76
Time with wrist deviation (flexion, extension)				
Never	129	1.00	Reference	
<2 h/day	85	**1.73**	1.09	2.76
2–4 h/day	102	**2.12**	1.39	3.23
>4 h/day	352	**1.96**	1.35	2.83
Time with wrist deviation (ulnar, radial)				
Never	211	1.00	Reference	
<2 h/day	102	**1.67**	1.16	2.40
2–4 h/day	95	**1.96**	1.39	2.76
>4 h/day	257	**1.75**	1.29	2.35
Time spent gripping, holding, or controlling objects forcefully with the fingers				
Never	203	1.00	Reference	
<2 h/day	79	1.39	0.95	2.05
2–4 h/day	80	**1.72**	1.22	2.44
>4 h/day	302	**1.61**	1.21	2.14
How often is personal protective equipment (PPE) worn to prevent cuts/lacerations†				
Never, not necessary in this job	55	1.0		
Never, because it's too hot, uncomfortable, poorly fitting, gets in the way, not readily available for use, etc.	115	**1.92**	1.10	3.34
Sometimes, but not full 8 h	92	**2.21**	1.42	3.46
All the time, full 8 h of work time	39	1.58	0.99	2.54
Difficulty in maintaining work pace for 8-h day				
Not difficult	289	1.00	Reference	
A little difficult	287	1.21	0.96	1.54
Somewhat difficult	123	**1.33**	1.01	1.76
Very difficult	23	**2.21**	1.32	3.70
Overall physical effort demanded by job				
Very light	50	1.00	Reference	
Fairly light	101	1.42	0.70	2.87
Moderate	402	**2.23**	1.15	4.30
Hard	117	**2.41**	1.19	4.87
Very hard	31	**2.64**	1.23	5.79

Bold-faced indicates $P < 0.05$.
* Surveys ($n = 743$) were included in the laceration analysis but not all people responded to every question; therefore, sample sizes do not always sum to 743.
† PPE use applies only to subjects who participated in the last survey, $n = 310$.

The majority of workers in this study were cut by stamped metal parts (eg, the washer cabinet and panels), whereas tooling and equipment were less common sources of injury. Sorock et al.[29] similarly reported that hand injuries (most of which were lacerations) are most commonly caused by metal items. Between the two routine worker groups (line-paced inspectors and mono-task assemblers), risk of hand laceration injury was significantly higher among the assemblers despite their greater reported continuous use of PPE. This result is consistent with our observational understanding of job conditions at this job site in which job performance among assembly workers required greater proximity to and handling of metal parts with exposed sharp edges and generally required a faster work pace and higher levels of exertion. Sorock et al[18] has also documented an increased risk of hand injury during times when workers were rushed.

The findings in this study concerning the level of job routinization are similar to results from two other studies. Hertz and Emmett[17] found that people who experienced a hand injury were more likely to report doing a non-usual task at the time of injury than were noninjured controls. Sorock et al[18] also found hand injuries to be significantly more likely to occur during the time when an unfamiliar task was being performed. In the current study, it was not known whether laceration incidents among those who rotate or those who perform more varied job functions were more likely to occur shortly after transitions between jobs or task assignments. Further research is warranted to identify if there are factors associated with the transition period or with characteristics of rotating tasks that may account for an increased risk of injury among workers in non-routine or multi-task jobs. It would also be important to identify factors associated with PPE use patterns by routinization level.

It is possible that rotating between jobs, even at a fixed time interval, may also introduce a degree of unfamiliarity or uncertainty with task conditions. Alternatively, the increased risk found among workers who rotate may be due to the jobs within rotation patterns having greater physical requirements or due to workers who rotate being less likely to consistently wear PPE during the workday. We were unable to identify any studies reporting an association between job rotation and injury outcomes. Given the dramatic increase in the proportion of private sector firms employing job rotation, from 27% in 1992 to 56% in 1997,[30] it is important that employers recognize that the use of job rotation, which is often instituted to control the risk of musculoskeletal disorders, may introduce an unintended consequence in the form of increasing risk of laceration injuries.

The results of this study were also consistent with previous reports of the relationship between individual factors and hand injuries. No association was found between hand dominance and hand laceration rates, which corresponds with a recent review of the role of hand dominance on hand injuries among workers.[31] Age was inversely associated with laceration rates. Younger age has been found to be a risk factor for hand injuries in other studies.[17,32,33] However, age was significantly correlated with job tenure (or experience) in this study, which was found to be a strong predictor of laceration rate. The finding of increased risk of injury among less experienced workers has also been widely reported.[14,22,34,35] The studies showing a relationship between inexperience on the job with increased risk of injuries, however, do not also report the relationship between age and job experience. Distinguishing among risk factor conditions requires that they not be strongly correlated.[36] The crude rate ratios reported in this study, however, suggest that job experience is a more important predictor of hand laceration injury than age.

The relationship reported in this study between current smokers and laceration rates is consistent with previous studies showing that smokers are at an increased risk of occupational injury.[37,38] Although these other studies looked at total injuries[37] and musculoskeletal injuries,[38] our findings suggest that smokers may also be at higher risk for acute injuries. Smoking status was highly correlated with age and job tenure in this study so distinguishing among these risk factors is limited, however, it is important to note that smoking status was more weakly associated with the occurrence of lacerations.

The presence of upper limb musculoskeletal symptoms was associated with a higher risk of hand lacerations. Injury risk among workers with a more chronic musculoskeletal condition was not incrementally greater than symptomatic workers with lower symptom frequency or duration, suggesting that the association between musculoskeletal symptoms and hand lacerations was not dependent upon chronicity. This finding may reflect greater difficulty among workers with upper limb musculoskeletal symptoms to perform more controlled motor function, placing them at greater risk of injury. Similarly, Vlaeyen et al[39] suggest that workers who experience pain may fear exacerbation of pain, affecting their movement patterns. Because of the cross-sectional nature of the study data, it was not determined whether musculoskeletal symptoms are a risk factor for laceration injuries or whether this association reflects a comorbid condition among workers exposed to working conditions that place them at risk for both laceration and musculoskeletal injuries. Further research is warranted to delineate the nature of this association.

Limitations of this study include the lack of a severity measure in the definition of lacerations. Because we did not have severity indicators, it is difficult to directly compare the high rate of injury (83 hand laceration injury incidents per 100 workers per year) in this study population to other populations. However, a study of poultry slaughterhouse workers showed that 19% of workers reported lacerations during a single day,[40] suggesting that a high laceration rate is possible in an industrial setting. Other research has found that circumstances surrounding less severe injuries may be similar to those of more severe injuries.[14]

We were not able to determine if workers who reported both a hand and a finger laceration during the same survey period experienced these lacerations during the same incident. This is an unlikely scenario however. Unpublished data on locations of hand lacerations from Sorock et al's 2002 study[29] showed that 81 of 877 lacerations (9.2%) occurred at the same time, such as two fingers being cut, or a cut to both hand and fingers during same incident (Gary Sorock, personal communication). We believe the laceration rate reported in our study may actually be underestimated, since we were not able to determine if multiple lacerations occurred to the same body part (such as two lacerations to the fingers) during each survey period. Record-based laceration data at the site of this study were too sparse to include in our analyses. There is no requirement for employers to record laceration occurrences involving minimal first aid treatment. Furthermore, workers' injury and illness reporting behavior can be influenced by factors other than severity, including fear of reprisal from the employer and cultural norms. The rate of new workers employed at the worksite increased during the study, and new workers may have greater reservation about reporting injuries to an employer while on probationary status or they may lack familiarity with reporting procedures.

Although routinization, the main workplace risk factor examined in this study, was assessed from the combination of data gathered from direct observational analysis of job tasks and discussions with key informants, data used in this analysis concerning worker exposure to specific biomechanical stressors were based on workers' self-reported exposure. However, alternative assessment techniques (ie, direct observation and accelerometry) were employed as criterion measures to inform the convergent validity of these measures. Favorable agreement was shown for all of the self-reported measures used in analyses reported in this paper.[41,42] Although the self-reported physical stressor measures used may lack precision, the general relationship patterns reported in Table 3 are believed to be accurate.

Another potential limitation of this study is the denominator data used in the rate calculations, which was based upon the number of days employed in the current job, as opposed to the more common use of the number of work hours. We believe the use of "days" in the rate calculation provides a reliable estimate of each workers exposure time because the study population consisted only of full-time workers, where work hours between workers vary little due to the interdependent task structure of the assembly line.

Personal protective equipment was the primary method used at the study site to control worker exposure to the large number of sharp metal objects in the work environment. The rate of lacerations was high despite the ready availability of PPE among the workforce. Workers in more varied job assignments were found to be less likely to wear PPE consistently throughout the workday. Gloves and finger tape were the most commonly used PPE by this workforce, and non-use was most often attributed to interference with task performance and poor fit.

To reduce the high prevalence of laceration rates in industrial environments, emphasis should be placed on engineering solutions to control the production of fabricated parts with sharp edges and to otherwise provide effective contact barriers. Examples of engineering controls to reduce laceration risk could include more frequent die maintenance (eg, sharpening), reduced die tolerance limits to reduce the formation of metal burrs, the substitution of laser cutting technology to provide more dulled edges, the application of tape to sharp edges to provide a contact barrier, and process design improvements to decrease the amount of metal part handling. In addition, it is important that workers receive ample training in hazard identification prior to new job assignments and that, when PPE is required, that multiple sizes are available to promote good fit and enhanced compatibility with assigned tasks. The findings of this study show that it is especially critical to target new workers at the worksite, and those in more variable job functions, for injury prevention training.

Acknowledgments

The authors would like to express appreciation to those who provided assistance in the collection of data at the study site: Cherie Estill, Marie Haring Sweeney, Dan Farwick, Frank Stern, Jim McGlothlin, Steve Smith, Paula Ludwig, Chris Zimmermann, Laurie Piacitelli, Bob Roberts, Victor Paquet, Beth Atkins, Larry Fine, Bill Ehling, Glenn Doyle, Dan Watkins, Ron Kovein, Brian Lowe, Rick Cassinelli, Nathan Vincent, Michael Box, Kim Jenkins, and BJ Haussler. The authors would also like to thank BJ Haussler and Kathy Watkins for assistance in questionnaire design, coding, and entry verification and to Dave Hilling and Scott Hendricks for programming assistance and statistical advice. The authors would also like to thank the management, local union, and all workers at the study site for their facilitation of this research. Special thanks goes to Cherie Estill, who initiated the research at the study site. Thanks are also extended to Mark Boeniger for consultation on the impact of dermal barrier degradation on increased susceptibility to the effects of allergens and other toxins; to Cherie Estill and Dan Hartley for their review of an earlier version of this manuscript; and to Gary Sorock and an anonymous reviewer, who also provided helpful suggestions for the manuscript.

References

1. Schelp L, Svanström L. One-year incidence of occupational accidents in a rural Swedish municipality. *Scand J Soc Med.* 1986;14:197–204.
2. Harker C, Matheson AB, Ross JA, Seaton A. Occupational accidents presenting to the accident and emergency department. *Arch Emerg Med.* 1992;9:185–189.
3. O'Sullivan ME, Colville J. The economic impact of hand injuries. *J Hand Surg Br.* 1993;18:395–398.
4. Williams, JM, Higgins D, Furbee PM, Prescott JE. Work-related injuries in a rural emergency department population. *Acad Emerg Med.* 1997;4:777–781.
5. Centers for Disease Control and Prevention (CDC). Surveillance for nonfatal occupational injuries treated in hospital emergency departments—United States, 1996. *MMWR.* 1998;47:302–306.
6. McCaig LF, Burt CW, Stussman BJ. A comparison of work-related injury visits and other injury visits to emergency departments in the United States, 1995–1996. *J Occup Env Med.* 1998;40:870–875.
7. McCurdy SA, Schenker MB, Lassiter DV. Occupational injury and illness in the semiconductor manufacturing industry. *Am J Ind Med.* 1989;15:499–510.
8. Frumkin H, Williamson M, Magid D, Holmes JH, Grisso JA. Occupational injuries in a poor inner-city population. *J Occup Env Med.* 1995;37:1374–1382.
9. Banco L, Lapidus G, Monopoli J, Zavoksi R. The safe teen work project: a study to reduce cutting injuries among young and inexperienced workers. *Am J Ind Med.* 1997;31:619–622.
10. Driscoll T, Hanson M. Work-related injuries in trade apprentices. *Aust NZ J Public Health.* 1997;21:767–772.
11. Wu TN, Saou SH, Hsu CC, et al. Epidemiologic study of occupational injuries among foreign and native workers in Taiwan. *Am J Ind Med.* 1997;31:623–630.
12. Warner M, Baker SP, Li G, Smith GS. Acute traumatic injuries in automotive manufacturing. *Am J Ind Med.* 1998;34:351–358.
13. Courtney TK, Webster BS. Disabling occupation morbidity in the United States: an alternative way of seeing the Bureau of Labor Statistics data. *J Occup Env Med.* 2001;41:60–69.
14. Sorock GS, Lombardi DA, Courtney TK, Cotnam JP, Mittleman MA. Epidemiology of occupational acute traumatic hand injuries: a literature review. *Safety Sci.* 2001;38:241–256.
15. Meneghini CL. Sensitization in traumatized skin. *Am J Ind Med.* 1985;8:319–321.
16. Wester RC, Maibech HI. Percutaneous absorption in diseased skin. In: Maibach HI, Surber C, eds. *Topical Corticosteroids.* Basel: Karger; 1992:128–141.
17. Hertz RP, Emmett EA. Risk factors for occupational hand injury. *J Occup Med.* 1986;28:36–41.
18. Sorock GS, Lombardi DA, Hauser RB, Eisen EA, Herrick RF, Mittleman MA. A case-crossover study of occupational traumatic hand injury: methods and initial findings. *Am J Ind Med.* 2001;39:171–179.
19. Baron S, Hales T, Hurrell J. Evaluation of symptom surveys for occupational musculoskeletal disorders. *Am J Indust Med.* 1996;29:609–617.
20. Occupational Safety and Health Administration Draft Ergonomic Protection Standard, Appendix A (Workplace Risk Factor Checklists). Washington, DC: US Department of Labor, OSHA; March, 1995.
21. Varghese M, Saha P, Atreya N. A rapid appraisal of occupational workload from a modified scale of perceived exertion. *Ergonomics.* 1994;37:485–491.
22. Schoemaker MJ, Barreto SM, Swerdlow AJ, Higgins CD, Carpenter RG. Nonfatal work related injuries in a cohort of Brazilian steelworkers. *Occup Environ Med.* 2000;57:555–562.
23. Cumming RG, Kelsey JL, Nevitt MC. Methodologic issues in the study of frequent and recurrent health problems. *Ann Epidemiol.* 1990;1:49–56.
24. Frome EL. The analysis of rates using Poisson regression models. *Biometrics.* 1983;39:665–674.
25. SAS. The GENMOD procedure. SAS Technical Report P-243. 1993. Cary, NC: SAS Institute Inc.
26. Bailer AJ, Reed LD, Stayner LT. Modeling fatal injury rates using Poisson regression: a case study of workers in agriculture, forestry, and fishing. *J Safety Res.* 1997;28:177–186.
27. Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika.* 1986;73:13–22.
28. SAS. SAS/STAT software: changes and enhancements for release 6.12. Cary, NC: SAS Institute, Inc; 1996.
29. Sorock GS, Lombardi DA, Hauser RB, Eisen EA, Herrick RF, Mittleman MA. Acute traumatic occupational hand injuries: type, location, and severity. *J Occup Env Med.* 2002;44:345–351.
30. Osterman P. Work reorganization in an era of restructuring: trends in diffusion and impacts on employee welfare. *Ind Labor Relat Rev.* 2000;53:179–196.
31. Mackenzie K, Peters M. Handedness, hand roles, and hand injuries at work. *J Safety Res.* 2000;31:221–227.
32. Centers for Disease Control and Prevention (CDC). Occupational finger injuries—United States, 1982. *MMWR.* 1983;32:589–591.
33. Jensen R, Sinkule E. Press operator amputations: is risk associated with age and gender? *J Safety Res.* 1988;19:125–133.
34. Laflamme L, Menckel E. Aging and occupational accidents: a review of the literature of the last three decades. *Safety Sci.* 1995;21:145–161.
35. Gardner LI, Landsittel DP, Nelson NA. Risk factors for back injury in 31,076 retail merchandise store workers. *Am J Ind Med.* 1999;150:825–833.
36. Stevens J. *Applied Multivariate Statistics for the Social Sciences*. 3rd ed. Mahwah, New Jersey: Lawrence Erlbaum Associates; 1996.
37. Ryan J, Zwerling C, Orav EJ. Occupational risks associated with cigarette smoking: a prospective study. *Am J Public Health.* 1992;82:29–32.
38. Tsai SP, Gilstrap EL, Cowles SR, Waddell LC, Ross CE. Personal and job characteristics of musculoskeletal injuries in an industrial population. *J Occup Environ Med.* 1992;34:606–612.
39. Vlaeyen JWS, Kole-Snijders AMJ, Boeren RGB, van Eek H. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. *Pain.* 1994;62:363–372.
40. Mergler D, Vezina N, Beauvais A, Everell J. A study of the effects of working conditions on the health of slaughterhouse workers. Hamilton, Canada: Canadian Centre for Occupational Health and Safety, Report No. 0475; 1984.
41. MacDonald L. Evaluation of intermethod agreement in the assessment of workers exposure to physical stressors in a mass production work environment. Doctoral Dissertation. Lowell, MA: Department of Work Environment, University of Massachusetts, Lowell; 2000.
42. Estill CF, MacDonald LA, Wenzl TB, Petersen MR. Accelerometers as an ergonomic assessment method for arm acceleration—a large-scale field trial. *Ergonomics.* 2000;43:1430–1445.