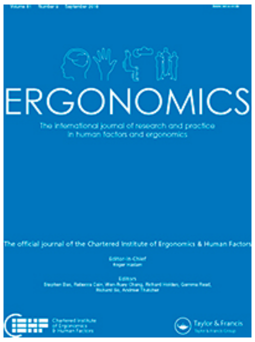

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Prospective validation of a low-back disorder risk model and assessment of ergonomic interventions associated with manual materials handling tasks

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Keywords: Industrial ergonomics; Low-back disorder risk; Validation; Workplace interventions; Manual materials handling.

The evaluation of low-back disorder risk associated with materials handling tasks can be performed using a variety of assessment tools. Most of these tools vary greatly in their underlying logic, yet few have been assessed for their predictive ability. It is important to document how well an assessment tool realistically reflects the job's injury risk, since only valid and accurate tools can reliably determine whether a given ergonomic intervention will result in a future reduction in back injuries. The goal of this study was to evaluate how well a previously reported low-back disorder (LBD) risk assessment model (Marras *et al.* 1993) could predict changes in LBD injury rates as the physical conditions to which employees are exposed were changed. Thirty-six repetitive materials handling jobs from 16 different companies were included in this prospective cohort study. Of these 36 jobs, 32 underwent an ergonomic intervention during the observation period, and four jobs in which no intervention occurred served as a comparison group. The trunk motions and workplace features of 142 employees performing these jobs were observed both before and after workplace interventions were incorporated. In addition, the jobs' LBD rates were documented for these pre- and post-intervention periods. The results indicated that a statistically significant correlation existed between changes in the jobs' estimated LBD risk values and changes in their actual low-back incidence rates over the observation period. Linear and Poisson regression models also were developed to predict a change in a job's incidence rate and the number of LBD on a job respectively, as a function of the job's risk change using this assessment model. Finally, this prospective study showed which ergonomic interventions consistently reduced the jobs' mean low-back incidence rates. These results support use of the LBD risk model to assess accurately a job's potential to lead to low-back injuries among its employees.

1. Introduction

The value of incorporating ergonomic principles into the industrial work environment to control musculoskeletal injuries, such as low-back disorders (LBD), has been debated extensively in recent years. The literature contains numerous descriptions of ergonomic risk assessment tools and techniques, and case

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studies abound that support the positive impact that ergonomic interventions have in the physical workplace (e.g. Garg and Owen 1992, Aarås 1994, US General Accounting Office 1997). Reported benefits of such interventions include lowering the numbers and costs of injuries, reducing discomfort and fatigue, and improving productivity. However, in some parts of the world these claims are viewed as contentious. Some contend that adequate proof of the benefits of ergonomics concepts does not exist for the control of work-related musculoskeletal disorders (i.e. Bigos *et al.* 1991, Hadler 1997). Critics of the ergonomic approach often site specific cases of workplace interventions that have not reduced the risk, or, even increased the risk, of LBD. Few workplace studies exist that have scientifically explored this issue.

Several risk assessment tools for the low back have been reported in the literature in recent years (Chaffin and Park 1973, NIOSH 1981, Snook and Ciriello 1991, Waters *et al.* 1993). Historically, these tools have been developed based upon hypotheses about how the low back is injured or consensus among different assessment techniques. However, few validation studies have been reported in the workplace to test whether these tools are indeed capable of predicting risk. This fact has been recognized by Viikari-Juntura (1997), who stated, 'The effect of various workplace interventions, attempting to optimise physical load factors, has had fairly little investigation'.

Only a few attempts have been documented to determine how well some of the aforementioned ergonomic tools identified a job's risk to the low back. Marras *et al.* (1999b) compared assessments of jobs using the 1981 and 1991 NIOSH lifting indices (NIOSH 1981, Waters *et al.* 1993) and the psychophysical limits (Snook and Ciriello 1991) with an independent database of manual materials handling (MMH) jobs. The 1981 NIOSH guide and the psychophysical approach lacked risk sensitivity, whereas the 1991 NIOSH lifting equation suffered from a lack of risk specificity. Waters *et al.* (1998) evaluated these tools to assess risk, as well as a three-dimensional Static Strength Prediction Program (Chaffin and Andersson 1994), an energy expenditure prediction program (Garg *et al.* 1986), and the use of heart rate and oxygen consumption. Considerable variability was identified in terms of how each tool estimated risk. Lavender *et al.* (1997) compared four LBD risk tools in the workplace and reported that they do not necessarily measure the same dimensions of low-back risk. This comparison found relatively low intercorrelations (range 0.06–0.42), suggesting that the tools were measuring very different qualities. This study did not relate the assessments to actual risk, indicating that they might have varying levels of validity. The results of these studies suggest that none of the ergonomic assessment tools mentioned had demonstrated its ability to predict reliably a job's level of risk in a prospective study.

Such validations are needed to optimize the design of the workplace. In today's competitive market one can ill-afford to make ergonomic improvements through trial and error. The cost of an incorrect ergonomic intervention is great in that not only are resources wasted on an ineffective risk countermeasure, but also control of the musculoskeletal risk can be delayed (often for years) before it is realised that the solution was ineffective. By this time, more employees have been injured, increased costs are incurred and a competitive advantage over the competition is delayed. Thus, there is a need to develop tools that can effectively describe the degree of risk associated with a workplace design and answer the question of how much exposure to workplace risk factors is too much.

As part of an ongoing research effort to understand low-back disorders, an ergonomic model for assessing LBD risk has been developed, using data from the lumbar motion monitor (LMM). Use of the LMM and LBD risk model as an ergonomic assessment tool, for a variety of repetitive MMH activities, has been documented (Marras *et al.* 1992, 1993, 1995, Gill and Callaghan 1996, Lavender *et al.* 1997). The model estimates the probability that a job will be a member of a 'high risk' group, that is, similar to jobs previously found to have high numbers of LBD associated with them.

This current effort was intended to explore the risk prediction capability of this assessment tool. Specifically, there were two objectives of this study. The first was to test the validity of the LBD risk model by prospectively tracking industrial MMH jobs and comparing both LBD risk and low-back incidence rates at baseline and following an ergonomic intervention to the job. Thus, it was sought to assess whether changes in documented biomechanical stressors (identified via the risk model) were associated with corresponding changes in LBD injury rates. The second objective was to assess the impact of specific categories of ergonomic interventions.

2. Method

2.1. *Approach*

The overall objectives of this study were achieved by simultaneously observing recorded LBD rates and predicted LBD risk over a longitudinal period of up to 10 years. During this time, one of two situations was studied — jobs where no workplace changes occurred over the observation period and jobs where ergonomic interventions were incorporated. Job characteristics (used for risk prediction) were assessed for all jobs, and for jobs where changes were made, historical LBD risk trends were monitored during both a pre- and a post-intervention observation period. The type of job change made also was noted.

2.2. *Description of the jobs monitored*

Thirty-six jobs were monitored in this study. They were gathered from 16 separate companies and consisted of a wide range of MMH activities. These jobs included the palletizing and depalletizing of various goods, casting of aluminium parts, forming of rubber products, feeding machines, installing tires on vehicles, cutting soap, moving spools of paper, cleaning parts, handling clothing, welding, processing food, and assembling a variety of consumer products. All jobs were repetitive in nature, in that employees performed the tasks continuously throughout the day, within job cycle times of 1 min or less.

In 32 of the jobs, monitoring was performed over an observation period that consisted of time intervals both before and after job interventions were introduced. These modifications were considered 'ergonomic' by the companies in that they were intended to reduce the jobs' musculoskeletal demands. The interventions included: the addition of lift tables, to raise and lower the products being handled; the installation of lift aids, to provide a mechanical assist in moving products; redesign of the work areas, to make the jobs easier to perform; and the installation of production equipment (e.g. new machinery, semi-automation) in an effort to ease the jobs' demands. All job interventions were designed by the companies and often were specified by employees who did not have formal ergonomics training. In addition to these 32 jobs, four jobs were monitored over the same period in which no changes were made to their materials handling requirements.

2.3. *Subjects*

A total of 142 employees participated in this study. Fifty-seven (71.9% male) were monitored in all jobs before the interventions took place, and 85 (78.8% male) were monitored after these changes were implemented. Roughly 10% of the employees were monitored both pre- and post-intervention. Although differences in trunk motions are known to exist across individuals, Marras *et al.* (1993) reported that this variability was more a function of job design than due to employee differences. Descriptive employee information of those who volunteered is presented in table 1. On average, employees were experienced in performing the jobs on which they were monitored, and they had been employed at their company for a considerable length of time. The anthropometric data indicated that this sample was typical of an industrial working population (Marras and Kim 1993).

2.4. *Data collection procedure*

An effort was made to identify companies considering making ergonomic changes to the jobs. A pool of 60 jobs initially was assessed using the LBD risk model and served as candidates for post-intervention analysis. Follow-up was not possible for 24 of the jobs as they no longer met the study criteria (job elimination, plant closure, process change to the point where materials handling was no longer performed, etc.). Thus, the data were not included in the results presented here, and the analyses were conducted on the remaining 36 jobs. The four jobs in which no intervention occurred were selected based on the random contact of companies who participated in Marras *et al.* (1993), and the identification of jobs where there had been no changes (ergonomic or otherwise) since the job was first monitored.

After a company agreed to participate, injury history records for the jobs were reviewed. This information required the review of several sources, including plant medical records, Workers' Compensation data, and Occupational Safety and Health Administration (OSHA) Form 200 logs, to determine and include only those injuries that were new cases and were actual and recordable low back strains. Reported LBD (i.e. overexertion, strains, sprains) were included; injuries from acute events (e.g. slips and falls, lacerations, contusions) were not used to determine incidence. Company personnel familiar with the jobs were questioned to ensure that the jobs had not changed during the time in which injury records were reviewed. Pre-intervention observation periods ranged from 3.3 to 10.5 years.

A team of researchers from the Biodynamics Laboratory at The Ohio State University then arrived on-site. The material handling components of the job(s) of

Table 1. Descriptive information of the 142 employees monitored.

		Pre-intervention (n= 57)		Post-intervention (n= 85)	
Variable	Units	Mean	SD	Mean	SD
Experience with the job	years	3.64	*4.16*	5.32	*5.26*
Time with the company	years	9.74	*7.70*	12.03	*9.14*
Age	years	35.11	*9.15*	38.94	*10.17*
Height	metres	1.74	*0.08*	1.75	*0.09*
Weight	Newtons	783.20	*145.96*	796.64	*171.10*
Job satisfaction	—	5.44	*2.40*	6.76	*1.97*

interest were reviewed, and employees who regularly performed the job and who were doing it at that time were asked to take part in the study. Subjects were randomly selected for this study; < 5% of those approached did not agree to participate. Volunteers gave informed consent, were asked questions about their history with the job and company, and were then measured to obtain anthropometric characteristics. Only individuals with no current low-back pain were monitored. Each employee was fitted with the LMM and accompanying harnesses and asked to return to the job. Employees performed their work for several minutes and on a number of job cycles before data collection began. This was done so the individuals could become accustomed to wearing the device and, thus, perform the job as usual. Then, the trunk motions of the individual and several other relevant workplace factors were recorded as five-to-ten cycles of each job task were performed. One-to-five employees were monitored for each job, though every effort was made to gather data on at least three individuals per job. All individuals were given T-shirts in exchange for their participation.

Data were collected following a job intervention when it was believed employees had become accustomed to the change. The average length of time before the post-intervention data were collected was ~19 months. The exact data collection protocol used pre-intervention was repeated following the job change. To obtain updated incidence rate information for the jobs monitored, each company was contacted at ~6-month intervals for 1–4.5 years.

2.5. *Apparatus*

An LMM gathered trunk kinematic data. It is a lightweight and portable tri-axial electrogoniometer affixed to the back of the employee (figure 1). The device measured the instantaneous position, velocity and acceleration of the lumbar spine relative to the thorax in the lateral, sagittal and twisting planes of the body. Its accuracy in recording trunk motions was reported by Marras *et al.* (1992). The base of the LMM was attached to a waist harness worn by the employee, and its 'spine' slid within a bracket mounted on a harness that fit over the shoulders. Signals from the LMM were transmitted to, and stored on, a portable computer via a digital telemetry system using customized software.

A heavy-duty scale weighed the objects handled by employees, and a force gauge measured the push/pull forces required during the exertion. A tape measure determined the horizontal distance from the employee's L_5/S_1 joint to the centre of the hands as materials were being moved. The tape measure also recorded other workplace factors such as the vertical origin and destination heights of the objects handled.

2.6. *Experimental design*

An interrupted time-series quasi-experimental design (Campbell and Stanley 1966) was used. With this approach, each job served as its own control before the intervention occurred. The impact, post-intervention, could then be compared with the baseline data.

The independent variable tracked in this study was the type of intervention incorporated into the job. Dependent measures consisted of the following measures:

1. The job's *LBD incidence rate*, adjusted per 100 full-time employees performing the job.

Figure 1. Lumbar motion monitor as worn.

2. *Physical workplace variables*, including the maximum external moment generated about the spine for each job (which was the product of the weight handled and the furthest horizontal distance from the employee's L_5/S_1 joint to the centre of the hands) and the job's lifting frequency (the total number of material handling tasks required of the job per hour and performed by each employee monitored on the job). Other measures recorded were the vertical start and finish heights of the loads as they were handled and task asymmetry. These variables were collected for use in the database but were found by Marras *et al.* (1993, 1995) not to distinguish between low- and high-risk jobs.
3. *Trunk kinematic variables* collected from the LMM. These included measures of the position, velocity, and acceleration for each job task and were recorded in three-dimensional space.
4. An assessment of the job using the *LBD risk* model. The LBD risk computation was based upon both workplace physical measures and trunk kinematic data. A combination of these variables determined the probability the job would be a member of a group of jobs previously found to have high numbers of LBD, or LBD risk (Marras *et al.* 1993, 1995). The five variables were maximum external moment; lift rate; maximum sagittal flexion, maximum lateral velocity and average twisting velocity.

5. Employee *satisfaction* with the job, on a one-to-ten (low-to-high) scale.

2.7. *Data analysis*

The data first were checked to ensure normality using the ShapiroWilks test. Estimates of LBD risk for each job then were computed using the model reported in Marras *et al.* (1993, 1995). In cases where a job had multiple tasks, maximum values were assessed for each of the five variables in the model, across all tasks comprising the job, to determine one measure of LBD risk. It is beyond the scope here to recount the specific procedure for calculating LBD risk; however, for a thorough description, see Marras *et al.* (1999a).

Several analyses compared the computed LBD risk value pre- and post-intervention with the change in incidence rate or other related outcome variables. For these analyses, the effect was calculated as the incidence rate difference due to the intervention. A weighting factor was assigned to each of the 36 jobs based on the amount of data used to compute each job's incidence rate. This factor consisted of the number of hours on the job to which all the employees were exposed over the course of a year and the number of years of medical records available from each company. The weight given to each individual incidence rate was in units of person-years of exposure, both pre-intervention ($PYrs_{pre}$) and post-intervention ($PYrs_{post}$). The formula computed the weighting for changes in incidence due to the intervention was:

$$\text{Weight factor} = (PYrs_{pre} \times PYrs_{post})/(PYrs_{pre} + PYrs_{post}). \qquad (1)$$

The formula gave increased weight to jobs having more injury history and also to jobs with a more equal balance of exposure pre- and post-intervention. These weighting factors were used in all analyses in which the outcome variable involved incidence rates. Before the intervention, the total number of person-years across the 36 jobs was 3202. After the job change, it was 1244 person-years. For the four comparison jobs, the total amount of medical information was divided into two equal time periods, and 'pre-' and 'post-incidence' rates then were computed.

To assess whether a change in LBD risk due to an intervention would correspond to a subsequent change in incidence rate, three statistical techniques were employed. First, a Pearson correlation between LBD risk change and incidence rate change was computed to evaluate the association between these two measures. This analysis tested the null hypothesis that the correlation between these two variables was zero. To help understand the nature of this correlation, descriptive analyses categorized the jobs according to the degree of LBD change that occurred with the interventions. Risk categories were derived from the initial data set of LBD risk from our original study (Marras *et al.* 1993). This previous work involved over 400 MMH jobs and provided benchmark values for categorizing jobs according to LBD risk. The data describing high risk (incidence rate > 12) and low risk jobs (incidence rate= 0) from that data set are shown in figure 2. In this data set, note that no jobs with LBD risk > 70% had zero low-back incidence associated with them. Thus, jobs having risks > 70% are referred to as 'high risk' jobs. In contrast, a large percentage of the jobs with LBD risk of 30% or less reported no low-back disorders, and these were considered 'low risk'. The remaining jobs, having LBD risk between 30 and 70%, were considered 'medium risk.'

Second, to develop more specific quantitative relationships between these variables, a bivariate linear regression model was developed with the outcome variable being the change in incidence rate following the intervention, and two

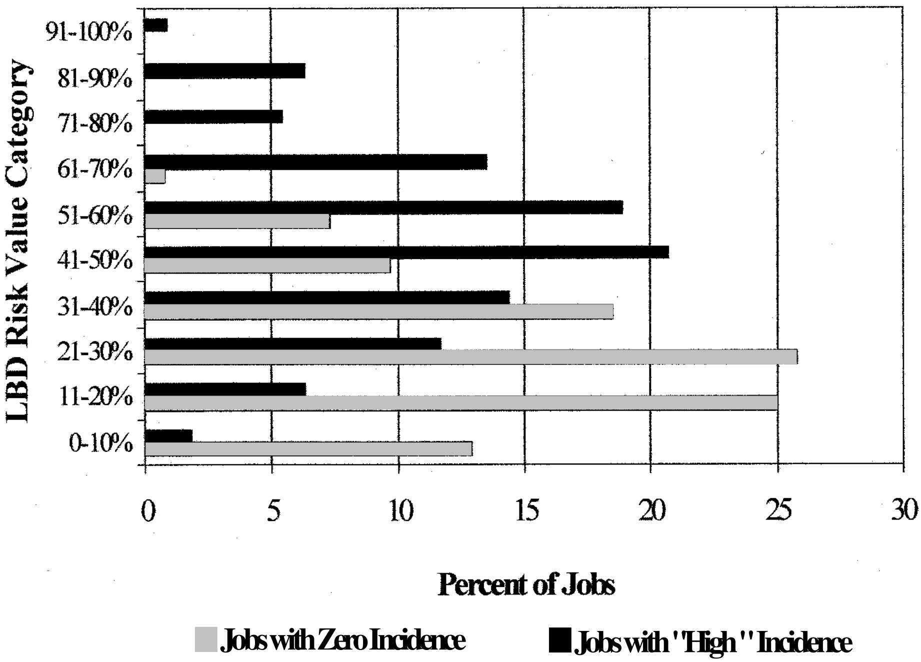

Figure 2. LBD risk distribution of jobs having either low or high incidence rates (data from Marras *et al.* 1993).

predictors being LBD $risk_{pre}$ and LBD $risk_{post}$. This model allowed for prediction of the incidence rate change based on separate values of LBD risk (those pre- and post-intervention), while the univariate model (the correlation) only considers the difference in LBD risk. The fit of the bivariate regression model was checked by plots of residuals versus fitted values, quantile plots of residuals and Cook's D (Rawlings 1988).

Finally, Poisson regression further evaluated this relationship. Analysis was performed since the aforementioned linear regression model required an outcome variable being approximately normally distributed (e.g. change in incidence rate). The Poisson approach considered the outcome variable as the number of low-back incidences on a job, post-intervention. This was numerical, that is, it took on 0, 1, 2, etc. The method of Poisson regression was appropriate to model the distribution of this variable as a function of one or several predictors. The method of maximum likelihood was used to fit the Poisson regression model. The model and techniques of fitting, checking and interpreting it are discussed in McCullagh and Nelder (1989). To supplement and check the statistical validity of the weighted linear regression analysis, several Poisson regression models were run using various combinations of the predictors Incidence $Rate_{pre}$, LBD $risk_{pre}$, LBD $risk_{post}$, and numerical and relative differences in LBD risk. Plots of deviance and Pearson residuals were used to check model fit. Computations were carried out using the general linear model function in the statistical programming language S+ Version 5.1 (Statistical Sciences 1999).

A second set of evaluations tested whether the ergonomic interventions would produce significant changes in the jobs' LBD rates. Thus, for all outcome variables, mean differences due to the interventions were computed, for jobs grouped by type of intervention. Two-sample *t*-tests with the pooled estimate of variance examined whether a change in the mean of a variable due to the intervention was significantly different from the change in the comparison group of four jobs in which no intervention occurred. Job weights were used as defined above for the tests involving incidence rate. For the seven workplace, trunk kinematic and psychosocial variables reported here, unweighted means were computed.

3. Results

Descriptive information characterizing the 36 jobs is shown in table 2. These jobs were grouped according to the type of intervention implemented. These data include exposure time, number of new low-back cases and LBD rate, and the LBD risk for the jobs assessed. In most cases, values were higher in the pre-intervention data.

3.1. *LBD risk model validation*

The Pearson correlation coefficient between LBD risk differences and incidence rate differences was statistically significant ($r = 0.4707$, $p = 0.038$), indicating a positive and significant correlation between changes in LBD risk following an intervention and changes in the job's LBD incidence rate. This provides an initial indication that differences in workplace characteristics and associated employee trunk motions due to ergonomic interventions were associated with LBD in the workplace.

The nature of this relationship is further characterized in figure 3. It describes how changes in estimated LBD risk were associated with changes in observed LBD incidence rates as a function of the degree to which LBD risk was controlled in the pool of observed jobs. In figure 3, four sets of columns classify the jobs according to their post-intervention risk classification (labelled as 'LBD risk Category, Post-Intervention'). Post-intervention categories were high (LBD risk >70%); low (LBD risk < 30%); and medium risk (LBD risk between 30 and 70%). Additionally, the risk is shown associated with the comparison group of four jobs that did not undergo an ergonomic intervention. The other axis of figure 3 indicates the observed incidence rate (both pre- and post-intervention) and the estimated LBD risk (pre- and post-intervention). All pre-intervention measures of the job were medium-to-high risk, and all incidence rates were similar, $\sim$10–11 LBD per 100 full-time employees per year. Note the agreement between the changes in the pre- and post-intervention LBD risk and pre- and post-intervention observed LBD rates. Figure 3 shows that when the LBD risk model predicted little change in the risk, little change in the incidence rate actually occurred. When large changes in risk were estimated, large changes in the incidence rate occurred. Moderate changes in risk and incidence rates also agreed well. Finally, when there was no intervention, only small changes in the mean incidence rate and mean LBD risk occurred.

Table 3 reports the means and 95% confidence intervals for the data shown in figure 3. These confidence intervals for LBD risk and incidence rate overlap considerably for both the comparison group and those jobs remaining high-risk following the job intervention. A two-sample *t*-test confirmed there was no statistical significance between the means for either incidence rate or LBD risk in these two groups. However, there was little overlap among the group of 19 jobs defined as medium-risk post-intervention, and no overlap, and a wider separation, between confidence intervals for the seven jobs that were changed to low-risk. T-tests computations found both post-intervention incidence rates and LBD risk to be significantly lower than the comparison group for these two categories of jobs.

Table 2. Descriptive information for the 36 jobs tracked for this study. Jobs are separated according to the type of intervention put in place, and data for the comparison group also are included. Incidence rates are given per 100 full-time employees.

	Pre-intervention data					Post-intervention data			
Job	Person-years	No. of new low-back cases	Incidence rate	LBD risk	Intervention type	Person-years	No. of new low-back cases	Incidence rate	LBD risk
1	41.8	10	23.9	78.0	Lift table	12.5	2	16.0	78.0
2	27.0	5	18.6	68.0		16.3	0	0.0	53.0
3	21.0	3	14.3	67.0		3.8	0	0.0	54.0
4	19.3	2	10.4	62.0		13.2	2	15.1	60.0
5	111.9	11	9.8	78.0		80.4	2	2.5	60.0
6	141.8	13	9.2	82.0		19.2	0	0.0	43.0
7	80.0	6	7.5	82.0		63.8	1	1.6	42.0
8	19.3	1	5.2	66.0		13.2	0	0.0	56.0
9	66.0	17	25.8	91.0	Lift aid	30.2	3	9.9	43.0
10	14.3	3	20.9	60.0		1.0	0	0.0	27.0
11	35.9	7	19.5	75.0		14.2	0	0.0	49.0
12	13.3	2	15.0	60.0		3.7	0	0.0	37.0
13	21.0	3	14.3	80.0		11.2	0	0.0	27.0
14	24.0	3	12.5	72.0		7.8	0	0.0	25.0
15	139.5	16	11.5	43.0		69.0	5	7.3	6.0
16	103.5	10	9.7	56.0		93.2	5	5.4	41.0
17	21.2	1	4.7	72.0		10.9	0	0.0	27.0
18	138.0	6	4.4	69.0		124.2	3	2.4	52.0
19	53.1	8	15.1	85.0	Redesign	53.1	3	5.7	86.0
20	115.6	14	12.1	40.0		79.3	14	17.7	47.0
21	20.0	2	10.0	50.0		20.0	0	0.0	42.0
22	20.0	2	10.0	40.0		20.0	1	5.0	29.0
23	53.4	5	9.4	90.0		26.6	3	11.3	42.0
24	161.9	11	6.8	88.0		48.3	8	16.6	84.0
25	648.9	36	5.6	41.0		111.2	5	4.5	59.0
26	409.8	8	2.0	63.0		70.2	4	5.7	71.0
27	102.5	2	2.0	50.0		17.6	0	0.0	63.0
28	28.0	4	14.3	66.0	Equipment	12.0	0	0.0	54.0
29	101.3	7	6.9	84.0		59.7	7	11.7	67.0
30	105.8	6	5.7	95.0		13.5	0	0.0	76.0
31	52.9	3	5.7	64.0		13.5	0	0.0	24.0
32	36.8	2	5.4	78.0		29.7	1	3.6	73.0
33	129.8	18	13.9	69.0	None	22.2	3	13.5	76.0
34	80.9	9	11.1	42.0		16.8	2	11.9	34.0
35	22.7	2	8.8	65.0		22.7	2	8.8	65.0
36	20.0	1	5.0	45.0		20.0	0	0.0	38.0

The relationship between incidence and risk was further analysed using a bivariate linear regression model (table 4). From this model it was determined that both assessments of LBD risk (pre- and post-intervention) significantly contributed to predicting the change in a job's LBD rate. This finding indicates that, by determining the LBD risk associated with a MMH job both pre- and post-intervention, the difference in the *rate* of LBD expected on that job can be determined reliably. This linear regression analysis was appropriate because the outcome variable (difference in incidence rate due to an intervention) satisfied the analysis assumptions (as was confirmed by residual plots). In addition, the data were

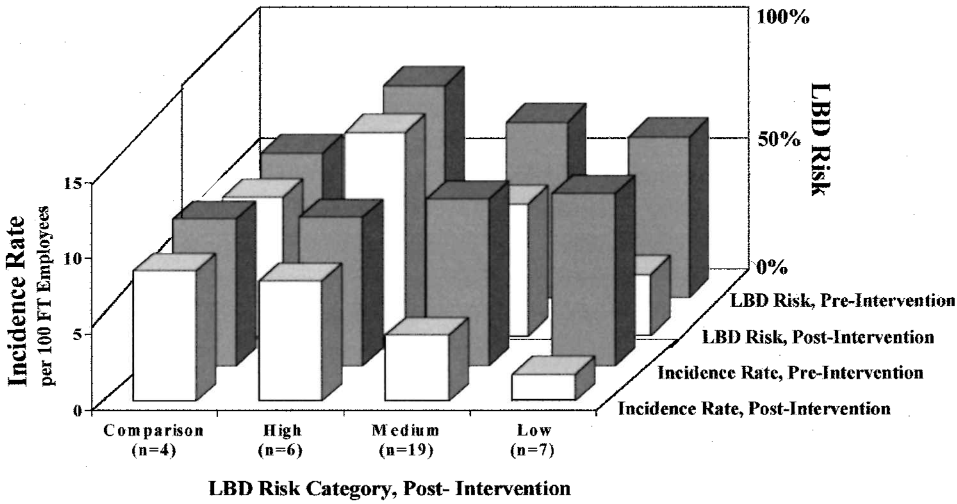

Figure 3. Differences in LBD risk and low-back incidence rates as a result of job interventions. The three categories of LBD risk following the intervention include: high (LBD risk $\geqslant$70%), medium (LBD risk between 30 and 70%) and low (LBD risk $\leqslant$30%). Differences are contrasted with changes in the comparison group, in which no job intervention was made.

Table 3. Means and 95% confidence intervals for the categories shown in figure 3. Data are presented for LBD risk computations and incidence rates, both pre- and post-intervention, grouped by the post-intervention LBD risk category.

	LBD risk category, post-intervention			
Comparison (n= 4) Mean *(95% CI)*	High (n= 6) Mean *(95% CI)*	Medium (n= 19) Mean *(95% CI)*	Low (n= 7) Mean *(95% CI)*	
55.2 *(33.4–77.1)*	81.2 *(69.6–92.7)*	67.2 *(59.8–74.6)*	61.6 *(47.6–75.6)*	LBD risk, pre-intervention
53.3 *(20.7–85.8)*	78.0 *(71.7–84.3)*	50.7 *(46.5–54.9)*	23.6 *(16.3–30.9)*	LBD risk, post-intervention
9.7 *(3.7–15.7)*	9.8 *(1.2–18.4)*	11.0 *(8.2–13.8)*	11.4 *(6.3–16.4)*	Incidence rate, pre-intervention
8.6 *(−1.0–18.2)*	7.9 *(0.8–15.1)*	4.3 *(1.5–7.1)*	1.8 *(−1.1–4.6)*	Incidence rate, post-intervention

weighted to account for differences in exposure time, particularly the smaller periods of time observed post-intervention.

Table 2 indicates that zero incidences were reported in several of the jobs for the post-intervention observation period. This could be due to the effects of the changes themselves or to the shorter post-intervention exposure periods. Thus, it was decided that a supplemental evaluation also was needed as a check of the linear regression analysis. A Poisson regression analysis was employed that allowed the zero incidence rates to be considered in the analysis. The resulting Poisson regression model reported here is shown in table 5. Using this analysis, two variables were used to predict the *number* of low-back incidences on a job post-intervention, consisting of

Table 4. Results of a weighted bivariate linear regression model to predict a job's incidence rate change due to an intervention. Both assessments of the job's LBD risk (i.e. pre- and post-intervention) significantly contributed to this model ($r^2 = 0.23$).

Variable	Parameter estimate	Standard error	t	p
Intercept	2.582	3.989	0.647	0.522
LBD $risk_{pre}$	0.136	0.061	2.216	0.034
LBD $risk_{post}$	–0.163	0.056	–2.889	0.007

Table 5. Results of the Poisson regression analysis, with the outcome variable, number of incidence following an ergonomic intervention, and two estimators, the pre-intervention incidence rate and the change in LBD Risk due to intervention. Incidence rates were weighted according to the years of job exposure that generated the LBD computation. Both predictor variables listed were statistically significant.

Variable	Parameter estimate	Standard error	t	p
Intercept	–0.524	0.234	–2.236	0.032
$Incidence_{pre}$	0.054	0.021	2.534	0.016
LBD risk difference	–0.018	0.007	–2.728	0.010

the job's pre-intervention incidence rate and the change in LBD risk following the intervention. Both measures significantly influenced this outcome variable. In addition, the plot of deviance residuals versus fitted values showed a satisfactory random appearance of these residuals. Thus, both the linear and the Poisson regression analyses presented indicate a clear association between incidence rate changes and computed LBD risk.

3.2. *Impact of ergonomic interventions*

A second goal of this study was to determine if the type of intervention employed had an effect on a number of outcome measures. In eight of the 36 jobs analysed, a lift table was used as an ergonomic intervention. In 10 of the jobs, a lift aid, such as an overhead pulley system or vacuum hoist, was put in place. For nine of the jobs, the work area was redesigned in some manner (e.g. improvements to existing manufacturing processes, use of various 'ergonomic' devices other than lift tables or lift aids) in an effort to produce a more efficient work arrangement and to reduce employees' exposure to suspected LBD risk factors. Five of the jobs involved the installation of new equipment (other than lift tables and lift aids) that the company believed would improve the jobs' productivity levels and reduce the physical workload required by employees. The remaining four jobs had not changed at all in terms of how they were structured and their work requirements, though data were collected at two different times. These four jobs served as the comparison group.

Table 6 describes the impact these interventions had on low-back incidence rates. The values were weighted according to the amount of exposure data available from the company. Of the specific intervention groups listed in table 6, half (lift tables and lift aids) resulted in a significant incidence rate reduction. Lift tables significantly reduced the mean incidence rate by 7.42 LBD per 100 full-time employees. Lift aids also reduced the LBD rates, by over six injuries per 100 full-time employees. The other job interventions (work area redesign and newly installed equipment) resulted in no significant improvements in incidence rate.

Table 6. Mean difference in LBD incidence rates, and corresponding confidence intervals, grouped according to the type of job intervention. T-testrs were computed in relation to the comparison groups of jobs in which no intervention was made.

			Incidence rate			
Type of Intervention	*N*	Mean difference	SD	95% CI	*t*	*p*
Lift table	8	7.42	*4.56*	6.74–8.26	2.70	0.001+
Lift aid	10	6.18	*5.52*	5.25–6.98	1.84	0.045+
Redesign	9	–1.11	*5.42*	–1.73 to –0.54	–0.69	0.253
Equipment	5	1.16	*6.28*	–0.10–2.58	0.09	0.464
None	4	0.85	*2.03*	0.28–1.38		

+ Statistically significancant at $\alpha = 0.05$.

Table 7 shows the impact of the specific types of interventions on the five workplace and trunk kinematic variables used in the risk analysis, as well as on the resulting LBD risk. Here, positive mean differences indicate that workplace and trunk kinematic variables were reduced following the interventions. Among the interventions studied, lift tables had the greatest impact on maximum sagittal flexion of the torso, significantly reducing the mean by nearly 30°. Lift tables also significantly reduced mean maximum lateral velocity (by nearly 16° s^{-1}). Lift aids reduced the mean external moment generated about L_5/S_1 (by well over 100 Nm) more than any other intervention studied. These devices, on average, resulted in a significant reduction in the computed LBD risk by nearly 35%. All of these mean differences were significantly greater than those observed in the comparison group over the observation period. Also indicated in table 7 was the fact that introducing new equipment as an intervention significantly reduced only maximum lateral trunk velocity. However, this reduction was of a large magnitude. Finally, the nine work area redesign interventions implemented by companies produced no statistically significant differences from the comparison group.

Differences in employee job satisfaction as a function of the interventions also are presented in table 7. Across all 32 jobs in which interventions were made, mean job satisfaction significantly increased (noted by the negative values). Of interest was the fact that the mean job satisfaction score for the comparison group decreased. However, none of the specific job interventions produced a significant change in reported job satisfaction, although the effect of lift aids approached significance ($p = 0.051$).

4. Discussion

Two significant goals were achieved here. First, using a prospective study design, the predictive value or validation of the LBD risk model, in terms of its association with low-back incidence rates, was established. Second, through this same experimental design, it was demonstrated that ergonomic job interventions could have a significant impact on reducing LBD in manual materials handling jobs. Each of these issues is discussed below.

4.1. *Validation of the LBD risk model*

This study has presented compelling evidence that LBD risk measure can reliably and quantitatively predict the effect that a job alteration will have on the low-back injuries rates of those exposed to the work. The univariate correlation between

Table 7. Unweighted trunk kinematic data, LBD risk, and job satisfaction values, grouped according to the type of job intervention. Mean differences indicate the values for these variables, with a positive value indicating a reduction following the intervention.

Type of Intervention	*N*	Max. external moment (Nm) Mean diff.	SD	*t*	*p*	Life rate (lifts/h) Mean diff.	SD	*t*	*p*
All interventions	32	38.94	*75.69*	0.29	0.772	33.58	*135.59*	0.93	0.358
Lift table	8	35.43	*34.86*	0.34	0.774	–3.69	*70.39*	0.69	0.509
Lift aid	10	112.40	*45.23*	3.17	0.008+	10.75	*102.51*	0.76	0.460
Redesign	9	–23.37	*83.06*	1.14	0.280	38.37	*131.22*	1.00	0.337
Equipment	5	9.79	*22.65*	0.78	0.463	130.22	*244.79*	1.28	0.242
None	4	27.58	*45.17*			–30.74	*47.81*		

Type of Intervention	*N*	Max. sagittal flexion (°) Mean diff.	SD	*t*	*p*	Max. lateral velocity (°/s) Mean diff.	SD	*t*	*p*
All interventions	32	17.00	*18.59*	1.42	0.164	12.20	*22.92*	1.62	0.114
Lift table	8	29.78	*11.32*	4.20	0.002+	15.81	*16.95*	2.47	0.033+
Lift aid	10	16.47	*16.42*	1.50	0.161	20.25	*33.91*	1.54	0.150
Redesign	9	5.65	*19.20*	0.21	0.836	1.23	*14.88*	0.99	0.344
Equipment	5	18.04	*22.18*	1.25	0.253	10.06	*8.50*	2.92	0.022+
None	4	3.52	*6.89*			–6.79	*8.74*		

Type of Intervention	*N*	Avg. twisting velocity (°/s) Mean diff.	SD	*t*	*p*	LBD risk Mean diff.	SD	*t*	*p*
All interventions	32	0.56	*5.80*	0.14	0.886	18.69	*19.53*	1.68	0.103
Lift table	8	–1.96	*2.44*	0.66	0.527	17.13	*15.10*	1.87	0.091
Lift aid	10	0.84	*5.11*	0.20	0.842	34.40	*13.71*	4.43	0.000+
Redesign	9	–1.34	*7.27*	0.31	0.760	2.67	*19.52*	0.07	0.949
Equipment	5	7.47	*2.18*	1.88	0.102	18.60	*13.13*	2.27	0.058
None	4	0.09	*8.55*			2.00	*6.98*		

Type of Intervention	*N*	Job satisfaction (1= low, 10= high) Mean diff.	SD	*t*	*p*
All interventions	32	–1.31	*2.23*	2.10	0.044+
Lift table	8	–1.59	*2.61*	1.85	0.094
Lift aid	10	–1.23	*1.83*	2.17	0.051
Redesign	9	–1.04	*2.26*	1.68	0.122
Equipment	5	–1.47	*2.92*	1.53	0.170
None	4	1.15	*1.92*		

+ Statistically significant at $\alpha = 0.05$

changes in LBD risk and low-back incidence was moderate but significant. This implies that not all the variability in incidence rate is related to the LBD risk. However, it does explain a significant, and probably the single largest, amount of variability. There are several factors that would be expected to under-represent this relationship and underestimate the correlation coefficient value. First, as stated above, companies differ greatly in their definitions of a recordable low-back injury. This variability in recording between companies would be expected to lower the correlation coefficient presented here, since the relationship between the risk measure and the recorded LBD incidence would be masked. One would expect that if a common operational definition for recordable LBD was employed across companies, this correlation would improve significantly. Second, the literature is clear in that LBD are truly multifactorial events. Other factors (such as personal variables and psychosocial influences) likely impact the numbers of low-back incidence reported by employees besides those involving the physical workplace. However, these factors were not examined extensively in this study. Third, LBD reporting is most likely related to job demands. Those performing physically demanding tasks would most likely not be able to continue working with a low-back injury and would therefore report the injury. However, those performing less physically demanding jobs may or may not report the injury. Many suspect that social pressures, organizational factors, and individual psychological factors play an important role in determining whether an employee reports the injury under these circumstances. Thus, more variability in reporting under the medium risk jobs would be expected. The data agree with this hypothesis (figure 2).

The validity of the risk model was further enhanced by the presence of a comparison group in this study. Since the comparison jobs did not produce a significant change in LBD incidence over the observation period, it can be concluded that changes in observed risk were due to workplace interventions and not to some external varying factor.

Despite the inherent variability in these data, the LBD incidence rate change that would be expected for a specific job was predicted, given an LBD risk assessment pre- and post-intervention. This was possible using both linear and Poisson regression models. The bivariate model is depicted graphically in figure 4 for several combinations of LBD risk. It shows that the larger the reduction in LBD risk following an intervention, the greater the mean predicted incidence rate drop will be. This is true, regardless of the initial LBD risk value (i.e. the job's risk pre-intervention). It should be noted that the magnitude of an intervention effect results in different incidence rate reductions, depending on the job's initial LBD risk level. For example, a job having an LBD risk of 90% that is reduced to 70% following the intervention could expect to produce a drop of just under four LBD per 100 full-time employees. This is still considered a 'high-risk' job (figure 2). However, a job having a moderately low LBD risk of 30% reduced by the same magnitude, to 10%, could theoretically expect to have a drop of well over five injuries per 100 full-time employees.

This bivariate linear regression also can accommodate situations where interventions can make jobs *more* likely to produce low-back injuries. This is indicated by a negative incidence rate change. For example, a job initially having a high LBD risk of 70% that, when changed to produce a higher 90%, could expect to observe two more LBD per 100 full-time employees per year than before the intervention. In contrast, a job change with a relatively low initial LBD risk of 30% that results in an increase to 50% following some job modification would only expect to see < 1.25 more injuries during the same amount of time.

The Poisson regression model developed from these results generates different information from the linear regression model (figure 5). This model predicts LBD *incidence*, given the incidence rate before an intervention and the estimated change in risk via the LBD risk model. The Poisson model predicted that the larger the reduction in LBD risk due to an intervention, the greater the drop will be in predicted incidence number. This change is moderated, obviously, by the baseline

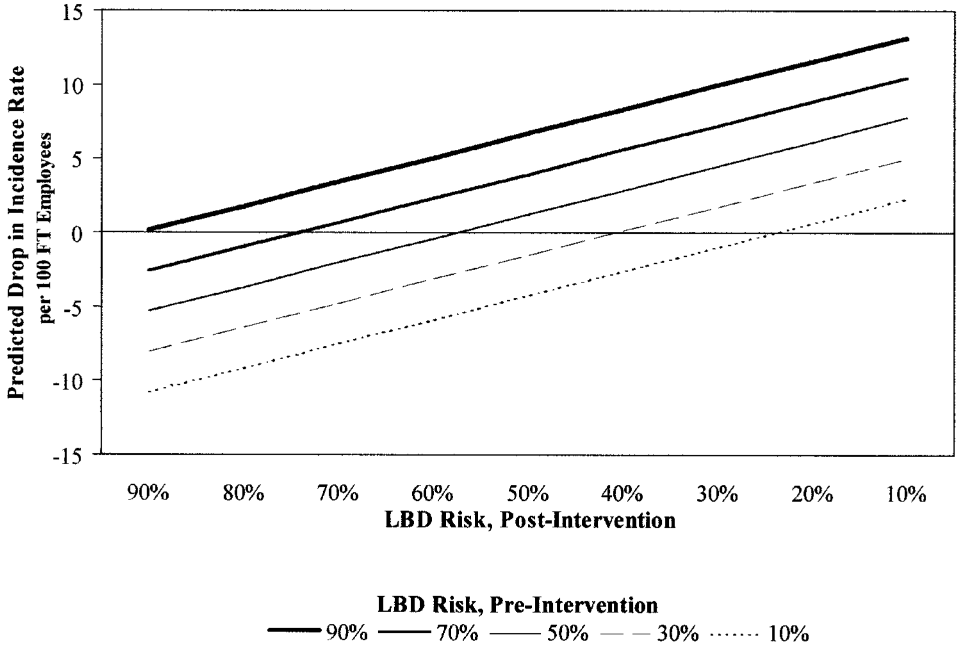

Figure 4. Representation of the bivariate linear regression model presented in table 4.

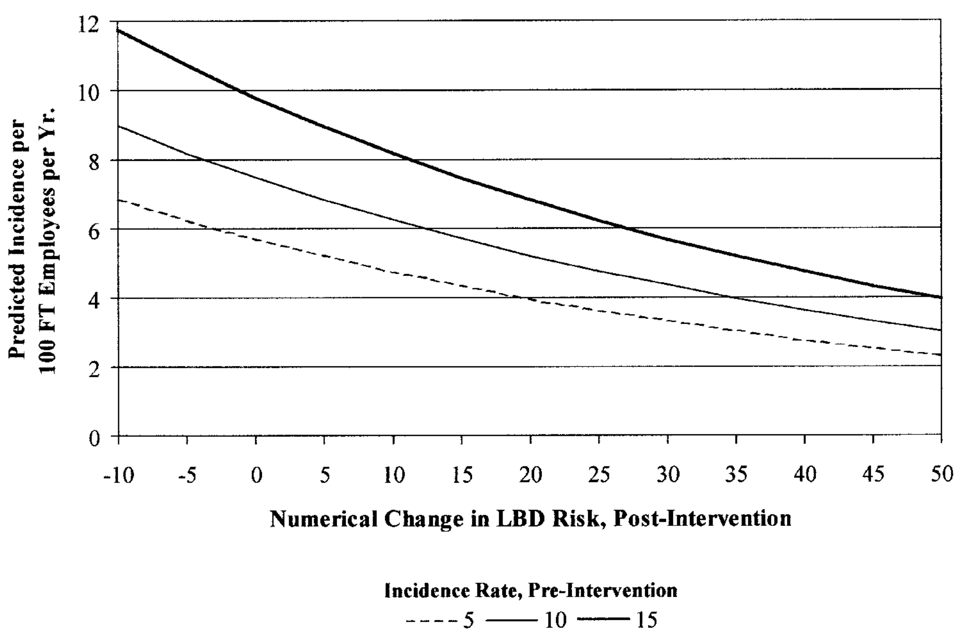

Figure 5. Graphical representation of the Poisson regression model presented in table 5. Positive post-intervention LBD risk indicate that LBD risk was reduced; negative values indicate the LBD risk assessment increased following the intervention.

incidence rate of the job. Figure 5 also shows the potential improvement gained by a job change that produces larger decreases in LBD risk from its pre-intervention value. For example, the same number of incidences (four per 100 full-time employees per year) is predicted by this model for three very different situations: (1) a job with initial incidence of five whose LBD risk is reduced by 20%; (2) a job with an initial incidence of 10 whose intervention reduces LBD risk to 35% below its previous assessment; and (3) a job with 15 low-back incidences per 100 employees whose intervention cuts its LBD risk by 50%. Thus, the risk relationship is non-linear. Finally, figure 5 shows that, for jobs with a zero change in LBD risk due to a workplace change, the model slightly overestimates its prediction for jobs having lower incidence and underestimates it for jobs with higher incidence. This suggests interventions having no risk value change could affect incidences differently, depending upon the pre-intervention incidence rate.

The primary benefit of these prediction models is that much more immediate feedback can be provided about job risk expectations following an ergonomic change. This risk assessment can address the issue of 'how much exposure is too much exposure to the risk factors'. By assessing a job change using the LBD risk model soon after the change is made, the employer can determine if the anticipated average drop in LBD is acceptable, if more should be done to improve further the operation, or if the job has actually been made worse. This may be a preferable approach compared with waiting several months or years to see if incidence rates actually change or drop to acceptable levels. This is particularly important for jobs traditionally having high incidence rates or for those jobs that employ large numbers of individuals, since their associated injury costs traditionally have more of an impact on the company.

4.2. *Impact of ergonomic interventions*

This study has demonstrated that a positive impact was observed for a number of interventions considered to be ergonomic in nature. However, these results also illustrated that not every type of intervention was successful in reducing a job's incidence rate. In this study, only lift tables (meant to bring loads upwards and closer to employees for handling) and lift aids (which sustain the weight of the load itself) were found individually to reduce LBD to a significant degree. Reported incidence rate reductions were significantly larger than the comparison group for lift tables and lift aids, with mean reductions of 7.42 and 6.18 LBD per 100 full-time employees per year respectively.

In the jobs examined here, redesign and equipment interventions did not reduce rates significantly differently from the comparison group. The impact of installing new equipment into work areas was slight, with an average drop of slightly more than one injury per 100 full-time employees yearly. The work area redesign interventions for the nine jobs tracked proved to actually *increase* the mean LBD incidence rate in the jobs observed.

This lack of effectiveness would have been predicted using the LBD risk model. Redesign of the nine jobs had no bearing on any of the measures of incidence rates, workplace or trunk kinematic variables, or employee satisfaction. Most of these jobs involved engineering changes (e.g. a change in the production process, a move to a supposedly 'improved' facility where the same job was performed within a new environment) that the company believed at the time would reduce the numbers of LBD. For the five jobs that involved the installation of new equipment, only mean maximum lateral velocity was significantly lower than for the comparison group. However, here again, the LBD risk model would have suggested that these interventions would not produce significant changes in risk.

These results do not imply that redesign and equipment interventions are ineffective. Indeed, table 2 reveals that a few of the redesign and equipment interventions did produce the desired results. This indicates that workplace redesigns and equipment interventions are probably capable of successfully reducing incidence rates, *if* ergonomics concepts are applied appropriately. However, this study demonstrated the possible lack of reduction in a job's incidence rate if companies do not consider ergonomics principles or do not correctly apply them in making job changes.

It should be emphasized that the interventions observed here were designed by the companies and not necessarily by professional ergonomists. Often persons with little or no ergonomic training were responsible for these designs. This situation serves to emphasize the need for quantification of workplace injury risk as well as quantification of the effects of potential job redesigns. The LBD risk model can fill this need.

The positive impact (in terms of injury reduction) of some job interventions observed here is also consistent with the biomechanical literature. Lift tables reduced the mean sagittal flexion and lateral trunk velocity values of jobs in which they were implemented. Reducing the extent of these awkward positions agrees with Punnett *et al.*'s (1991) findings, which showed that the time spent in non-neutral postures was strongly associated with LBD. The benefit of installing lift aids was drastically to lower the external moment generated about the lumbosacral joint. This outcome supports Burdorf and Zondervan's (1990) research, in which a significant relationship between heavy work and low-back pain was found in crane operators. Also, Videman *et al.*'s (1990) cadaver study found that those who performed heavy physical work had an increased risk of lumbar disc disease compared with those having mixed exposures to physical work.

The interventions themselves appeared to have an effect on what could be considered a psychosocial component of the jobs, too. The average job satisfaction score reported by employees (table 7), as contrasted with the comparison group, increased significantly following the intervention. This may be due to several influences. The physical requirements of the jobs themselves were reduced in many instances, and this may have translated to an improved view of the jobs' working conditions. A similar finding was reported by Marras *et al.* (1993), in that employees doing 'low-risk' jobs reported significantly higher levels of job satisfaction than did their counterparts performing 'high-risk' MMH activities. Even though most of the jobs in this study were monitored many months or years following the intervention, a type of 'Hawthorne Effect' may still have been present, in which a perceived change in the workplace was accompanied by a significant and positive change in employees' satisfaction with their work.

One potential concern in this study may be the difference in exposure data pre- versus post-intervention. This occurred primarily due to the changing nature of work in recent years. For example, only low-back injuries reported within the time frame in which a significant change was made to the jobs were used in the incidence rate computations. With today's increasingly competitive global economy, significant job modifications, ergonomic or otherwise, occur more frequently. In addition, modifications in manufacturing processes due to product changeovers also confined the period in which injury data could be tabulated. These factors limited the observation time for several jobs. However, adjustments in the data were made by weighting incidence rates based on the amount of exposure data that were available. Thus, from a statistical perspective this should not create a problem.

Another concern might be the number of jobs observed in this study and differences between employees pre- and post-intervention. While epidemiological studies often collect hundreds, if not thousands, of data points, this study was very different in that quantitative monitoring of employees was performed, which made collecting this size of data set impractical. However, a large number of employees (142) was observed, representing exposure time of nearly 4500 person-years. Thus, the impact of such concerns would be minimal in the statistical analysis. Finally, though the mean age and job experience of employees in the post-intervention group was statistically higher than in the pre-intervention sample, it was believed the difference (~1.5 years of experience and 4 years in age; table 1) had no practical relevance. This was confirmed when these variables were added to the regression models and added little to the explained variation.

5. Conclusions

Using a prospective design, this research has validated the use of an ergonomics assessment tool, the LBD risk model, and shown that it was capable of predicting changes in LBD incidence rates due to workplace interventions. The results presented have demonstrated a clear association between a job's risk level, assessed using the LMM both pre- and post-intervention, and the change in the expected numbers of low-back injuries. In addition, the study has shown the effectiveness of incorporating ergonomics into industrial operations. Specifically, it has demonstrated that certain ergonomic interventions, such as lift tables and lift aids, can significantly reduce the LBD rates of repetitive MMH jobs. This study also has shown that not all job changes, though initially believed to incorporate ergonomics principles, were effective in reducing injuries. Thus, for ergonomic interventions to be effective, they must be done correctly.

These findings are important to the field of ergonomics. It has been demonstrated conclusively that a significant link exists between a job's risk level and its low-back incidence rate. These results apply to a wide range of manual materials handling activities found in industries today, in which employees are required to handle a variety of objects repetitively in a manufacturing setting. Finally, this study has shown that ergonomic interventions, when applied according to known biomechanical principles, can be effective in reducing low-back injuries to employees.

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