ERGONOMICS, 2003, VOL. 46, NO. 9, 904–919

The effects of job rotation on the risk of reporting low back pain

MARDON B. FRAZER†*, ROBERT W. NORMAN†, RICHARD P. WELLS† and
W. PATRICK NEUMANN‡§

†Department of Kinesiology,
Faculty of Applied Health Sciences, University of Waterloo, Waterloo, Ontario,
Canada, N2L 3G1

‡National Institute for Working Life-West, Göthenborg, Sweden

§Department of Design Sciences, Lund Technical University, Lund, Sweden

Keywords: Job rotation; Low back; Biomechanical model; Cumulative loading; Administrative control.

Job rotation has been widely recommended as an administrative control to reduce the risk of developing work-related musculoskeletal disorders. However, evidence of its benefits are hard to find in the literature. The effect of job rotation on predictions for the risk of reporting low back pain was estimated using Low Back Pain Reporting (LBPR) and Time Weighted Average (TWA) approaches. Index scores calculated using the peak hand force, the peak L4/L5 shear force and the L4/L5 moment cumulated over the entire shift were used to estimate the effects of job rotation on the probability of reporting low back pain. Simulations of realistic rotations between two jobs showed that workers in low demand jobs who rotate into higher demand jobs experience a linear increase in reporting probability using the TWA approach. With the LBPR approach a step increase in reporting probability occurred because of the immediate exposure to the peak loading parameters associated with the more demanding job. With a 50–50 rotation the TWA and LBPR index scores increased by 39% and 57%, respectively. With the LBPR approach the redistribution of risk was not uniform with job rotation. The increase was greater for those who rotated into the demanding job compared to the reduction experienced by those who rotated out of the demanding job. The effects of job rotation are not easily estimated because of the complex effect that mixing jobs has on peak and cumulative tissue loading.

1. Introduction

Changes to the design of work that are intended to reduce injury and severity rates should be directed to reducing or removing known risk factors. High forces on tissues such as the discs, facet joints, ligaments and muscles of the low back have long been known to present high risk of injury. Recent research in the automobile assembly industry has shown that it is not only 'high peak' compression and shear forces on spinal tissues that are problematic but also 'high accumulations' of these forces over the course of a shift. Both peak and cumulative spinal loading are independent risk factors for the reporting of low back pain (LBP) (Norman *et al.* 1998).

---

*Author for correspondence. E-mail: frazer@uwaterloo.ca

Ergonomics ISSN 0014-0139 print/ISSN 1366-5847 online © 2003 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/0014013031000090161

Two general strategies for reducing the risk of developing work-related musculoskeletal disorders are engineering and administrative controls. Engineering controls involve physical manipulations of hazards or routes of exposure to physical hazards while administrative controls change the duties or the design of the job (Norman and Wells 2000). Engineering controls are the preferred strategy because they diminish the exposure. However, if an engineering control cannot be implemented immediately, or, not at all, than an administrative control may be used. Job rotation is frequently recommended as an administrative control for reducing musculoskeletal injury risk and fatigue (Jonsson 1988, Putz-Anderson 1988, Vander Doelen and Barsky 1990, Hazard *et al.* 1992, Wands and Yassi 1993, Grant *et al.* 1997, Kuijer *et al.* 1999). Many benefits have been ascribed to job rotation, including: a cross-trained workforce, increased motivation/innovation, reduced boredom and monotony, reduced work stress, reduced absenteeism, lower turnover rates, increased ability to handle change, increased production and reduced cumulative trauma disorders (e.g. Triggs and King 2000). However, a review of the literature did not find any studies which had rigorously evaluated job rotation in order to quantify its benefits in reducing risk factor exposure.

The general principle of job rotation is to alleviate the physical fatigue and stress for a particular set of muscles by rotating employees among other jobs that use primarily different muscle groups (US Department of Labour, 1993). For example, an employee may unload pallets at one workstation, primarily a low back challenge, and then rotate to another station and perform light assembly work, primarily an upper limb challenge. The rotation may occur at fixed intervals within a day, such as every 2 h, or changes may occur between days. Rotation schedules that involve different operational tasks but use the same muscle groups and joints in the same way from task to task cannot be expected to have a risk reduction benefit (Jonsson 1988, Van Velzer 1992, Wells *et al.* 1995).

It has been proposed that by decreasing the amount of time the same muscle groups and joints are exposed to loading, the physical workload is reduced for any one worker (Putz-Anderson 1988, Vander Doelen and Barsky 1990, Wands and Yassi 1993). It is assumed that by spreading high loads over several workers, rather than having the same worker exposed continuously to high risk, that the risk is averaged over the workforce and an overall reduction in risk occurs. Indeed, this may be the case for individuals who rotate out of high demand positions and decrease their exposure, but job rotation also requires that other workers rotate in to fill these positions. Therefore, rotation results in more individuals becoming exposed to the risk factors (Henderson 1992, Stoffman and Sykes 1999). In order to determine the effects of rotation on injury risk it is necessary to first quantify the risk of injury for performing those jobs that do not involve rotation but that would be included if a job rotation schedule were implemented. The risk of injury associated with performing the job(s) created by rotation must then be quantified. Comparing the injury risk estimates between these two scenarios allows the effects of job rotation to be evaluated.

The Low Back Pain Reporting (LBPR) approach is a strategy that the authors have developed, and are reporting in this paper, to ensure that both peak and cumulative spinal loading risk factors are considered when analysing a job. The strategy utilizes a custom software program (4D Watbak, University of Waterloo, Waterloo, ON, Canada) to quantify the peak and cumulative loading exposure experienced when performing a job for an entire shift. The magnitudes of these risk factors are then compared against the database developed by Norman *et al.* (1998) to produce a job specific risk estimate of the probability of reporting low back pain. In general terms this index is identified as Low Back Pain Reporting Index (LBPRI). When a specific risk estimate is calculated it is referred to as a LBPRI score (described in 2.3.4.). The LBPRI score is a risk estimate that may be used to evaluate the effects of job rotation on injury risk because it takes into consideration the demands of a job over an entire shift.

A common approach to estimate the risk of injury for working in a 'new job' created by job rotation is to average the risk between jobs. For example, if the risk of reporting a low back injury was 80% for Job no.1 and 40% for Job no.2, and a new job was created by having a worker spend one-half of their shift working in Job no.1 and the other half in Job no.2, averaging the risk would produce a risk estimate of 60%. This method of estimating the injury risk is actually a time weighted average (TWA) (Smith *et al.* 1991). The TWA calculation multiplies each of the job specific risk scores by the duration of time a worker spends at that job, as determined by the job rotation schedule, and then sums these products. This approach assumes a linear relationship between injury risk and exposure. However, this may not properly account for the specific peak and cumulative spinal loading exposures experienced in the 'New Job' because the demands required in performing this job have not been analysed collectively, as they would be if the 'New Job' were assessed as a separate job. This analysis is easily done using the LBPR approach and ensures that the amount of peak and cumulative loading associated with all of the specific tasks a worker performs are accounted for and reflected in the resulting LBPRI score. Analysing the new job in its entirety ensures that the redistribution of risk with job rotation is evaluated appropriately.

Both laboratory research results (Adams and Hutton 1985, Hansson *et al.* 1987) and workplace epidemiological evidence (Norman *et al.* 1998, Kerr *et al.* 2001) clearly implicate adverse effects of both high peak and high cumulative loading on tissues. The assessment of injury risk needs to consider these effects appropriately. The purpose of this research was to determine the effects that implementation of job rotation would have on: (1) the predicted risk of reporting of low back pain, as estimated using the TWA and LBPR approaches, and (2) the redistribution of predicted risk for those involved in the rotation schedule.

2. Methods

2.1. *The jobs*

Two jobs from an automotive assembly operation were selected for analysing the effects of implementing job rotation. The assessment of these jobs was conducted as part of an analysis investigating the postural demands for a series of work stations. These specific jobs were selected because of the considerable torso postural differences observed between them. The work performed in Job A occurred primarily near the outside of the vehicle and involved the selection and placement of panels. Job B required work to be performed at the front door post, in the driver's foot well and in the centre of the vehicle, with considerable forward bending and reaching. Both operators performed their jobs in standing postures.

2.2. *Job analysis*

Due to production requirements only the primary line operator ($n = 1$) could be observed performing each job. Approximately 30 production cycles were video taped from several view points so that representative postures could be defined for each of the actions that the production option mix required. The duration for each action was obtained from the industrial engineering standard line balance assessment data. Each of the tools and parts that the operators worked with were weighed using a digital force gauge, (DFI500, Chatillon, Raleigh, NC, USA). Forces acting on the hands were considered to be zero for activities that involved minimal hand forces (e.g., joining connectors). Support forces acting on the operators, such as an operator leaning on an elbow while joining a connector, were also assumed to be zero.

2.3. *Software*

2.3.1. *General overview*: The custom software utilized in this study was developed to: (1) estimate the moment of force and reaction forces for the major body joints (in particular the lumbar spine), for all of the actions required in performing a job, and (2) to predict the probability of a low back pain report being associated with that job. The core components of the software are a biomechanical model (described in 2.3.2.) and a database of peak and cumulative (dose/response) curves for spinal loading. The software requires inputs as described in 2.3.3. that are collected in the field so that biomechanical estimates may be made of the magnitude of the peak and cumulative spinal loading parameters. These values are used in conjunction with the database to generate the software outputs described in 2.3.4. which are the predictions of the probability of a low back pain report being associated with that job.

2.3.2. *Biomechanical model*: To estimate the moment of force and reaction forces for the major body joints a quasi-static, two dimensional, fifteen-link segment biomechanical model was used in the software. This model has been described in detail in earlier publications (Andrews *et al.* 1997, Norman *et al.* 1998). The model allows analysis of postures that are asymmetrical in the sagittal plane and/or involve asymmetrical hand forces. Reaction forces and moments are calculated by beginning at the wrist of each arm and then proceeding to the elbow, shoulder, seventh cervical vertebrae and down to L4/L5. A single extensor muscle equivalent with a 6 cm moment arm at L4/L5 is used in the calculation of the joint compression and shear forces.

2.3.3. *Model inputs*: In the field it is necessary to collect specific parameters related to the job and the worker in order to permit estimates of the sizes of both peak and cumulative spinal loading risk factors to be made. The duration, or shift length, of the job to be assessed, excluding rest and meal breaks, must be known. The job must then be divided into its discrete tasks. Each task may consist of single or multiple action(s). For each action a representative posture for the trunk, arms and legs is recorded (e.g. using photographs, video or an observational check list). Also, the magnitude and direction of any forces acting on each hand must be documented for each action. In order to quantify cumulative loading it is necessary to know the total amount of time per shift for which each action is performed. If this value is not known then the duration and number of repetitions of each action performed per shift should be recorded.

The anthropometric information (gender, height and weight) for a specific individual may be entered or default values for 5th, 50th, 95th percentile individuals (Canadian population) may be selected (FASC 1986). For each action, a computer manikin is manipulated so that the posture of the trunk, arms and legs matches that recorded. The magnitude and direction of the forces acting on each hand are then entered. For example, when lifting a 3.0 kg load in two hands, a 14.7 N force, acting down in the vertical direction would be entered in for each hand. Finally, for each action it is necessary to enter either the total duration of time per shift or the duration per repetition and the number of repetitions per shift. The total working time per shift which has been accounted for is determined by summing the times across all of the actions. Typically an analysis will not account for the entire shift because of variations in measuring action durations, task breakdown, time spent waiting, etc. For any unaccounted shift time the worker is assumed to be in an upright standing posture.

For each action, the biomechanical model estimates the L4/L5 moment of force, compression and shear. Multiplying these values by the duration and number of repetitions performed per shift determines the cumulative loading for each action. This time history is then modelled as a series of square wave pulses (Norman *et al.* 1998). The software then scans across all of the actions and records the peak hand force, L4/L5 moment of force, compression and shear. The cumulative spinal loading for moment, compression and shear is then obtained by summing the magnitude of each factor across all of the actions.

2.3.4. *Model outputs*: The reporting of LBP based on the peak and cumulative risk factors is predicted quantitatively using a Low Back Pain Reporting Index (LBPRI). The LBPRI ranges from 0.0 to 1.0 and represents the probability of a job being classified as a 'Case Job' (one associated with a LBP report) in the Norman *et al.* (1998) study if a worker had been working with that particular level of exposure at a job in the automotive plant in which the database was developed. For each job analysed, a specific individual LBPRI score is calculated for the peak hand force and the peak and cumulative L4/L5 spinal load factors of moment of force, compression, and shear. To obtain a LBPRI score, the magnitude of each parameter is compared to a database of 'dose/response' curves that plot the size of the risk factor parameter (the 'dose') against the probability of the job being classified a 'Case Job' (the 'response'). The curves were obtained from logistic regression analysis of more than 1175 assembly and assembly support tasks performed by 235 workers in an automotive assembly facility. They were part of a case/control study investigating risk factors for reporting low back pain (Norman *et al.* 1998, Kerr *et al.* 2001).

The curve for Peak Lumbar Compression is indicated in figure 1 as an example. As the peak compression associated with a job increases, the probability of being in the 'Case' group increases and this is reflected by increases in the LBPRI score that would be calculated. The univariate odds ratio for this risk factor is 1.9, based on the inter-quartile spread of the random controls (Norman *et al.* 1998). The other peak (hand force, moment and shear) and cumulative (moment, compression and shear) risk factors display similar relationships. Therefore, when the software is determining LBPRI scores, a separate curve is being used for each of the risk factors.

In order to facilitate analysis and interpretation, a single score, which provides an overall assessment of the job by simultaneously taking into consideration both peak

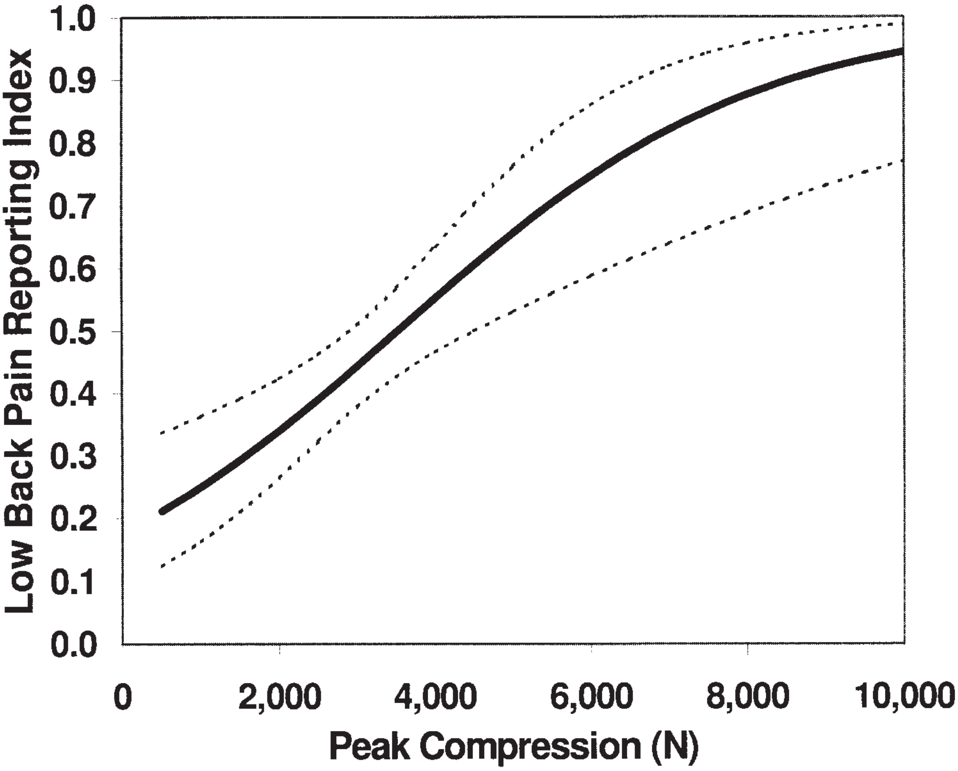

Figure 1. The Low Back Pain Reporting Index (LBPRI) curve for peak compression (solid line) and the 95% confidence intervals (dashed line). The greater the dose (peak compression), the greater the response (probability of reporting low back pain) or LBPRI score that would be calculated (Norman *et al.* 1998).

and cumulative risk factors, is also computed. This is termed a 'Combined LBPRI' score and is calculated by using the magnitudes of the peak hand force, peak shear and cumulative moment as inputs into a multiple logistic regression equation. The output of the multiple logistic regression equation depends upon three independent inputs so that a curve, such as figure 1, cannot be graphed. The univariate odds ratios for these risk factors are 1.8, 2.3 and 1.6, respectively, based on the inter-quartile spread of the random controls (Norman *et al.* 1998).

Norman *et al.* (1998) identified a four factor model which provided the best overall assessment of a job. This model included two peak (shear and trunk velocity) and two cumulative (moment and usual hand force) variables and ideally this model would have been incorporated into the software for calculating the Combined LBPRI score. However, peak trunk velocity is a kinematic variable which cannot be obtained from the software. When this parameter was excluded from the logistic regression procedures, the three term model (peak hand force, peak shear, and cumulative moment) emerged from the analysis as the regression equation that provided the greatest predictive power. This three factor statistical model was incorporated into the software so that a Combined LBPRI could be directly computed from the available biomechanical model outputs.

2.4. *Assessment of job rotation*

Job A and Job B were each analysed using the LBPR approach to determine their respective Combined LBPRI scores. A 'new job' was created by using job rotation and evenly dividing a worker's time between the two jobs (50% at Job A, 50% at Job B). The TWA risk of this new job assignment was estimated by multiplying the Combined LBPRI score for each job by the duration of time spent working at the job and then summing the results (i.e. Combined LBPRI of Job A*0.50 + Combined LBPRI of Job B*0.50).

The new job was also analysed in its entirety using the software. This required that the job be broken down into its discrete tasks, with the appropriate repetitions, frequencies, postures and hand forces entered. However, the worker was now required to perform all of the tasks for Job A and Job B over the course of the shift, so the discrete task list now consisted of all the tasks performed for Job A followed by all of the tasks performed for Job B. This allowed a Combined LBPRI to be estimated by the software that was distinct for the specific amount of time spent performing each job.

Twelve job rotation scenarios (table 2) were utilized to assess the effects of job rotation on predicted risk and its redistribution. Eleven scenarios were created by incrementally decreasing the amount of time a worker would spend on Job A by 10% and increasing the amount of time spent at Job B by 10%. For example a 90–10 scenario indicates working at Job A for 90% of the time and at Job B for 10% of the time. This example would be analysed with TWA approach as: Combined LBPRI of Job A*0.90 + Combined LBPRI of Job B*0.10. The LBPR approach analysed this work distribution by calculating a Combined LBPRI score based on the number of repetitions of each action performed in Job A and Job B as determined by the task analysis. The twelfth scenario involved a worker spending 99% of their time in Job A and 1% in Job B.

Changes in the Combined LBPRI risk estimates due to job rotation, as determined using the TWA and LBPR approaches, allow the relative effects of job rotation to be evaluated for each of the jobs, in each of the job rotation scenarios. To evaluate the effects of job rotation in absolute terms it is necessary to consider all of the risk in the entire system. If the two jobs in this analysis are considered to represent a simple system, then an estimate of the total system level of risk for reporting low back pain is obtained by summing the risk estimates for each of the workers, in each of the job rotation scenarios and the effects of job rotation may be evaluated in absolute terms.

3. Results

3.1. *Job demands*

The cycle time in the automotive assembly operation was 67 s and the daily production target was 364 vehicles. A 50th percentile male (1.74 m, 76 kg) was selected for use in the biomechanical model. Job A consisted of four tasks ranging from 1 to 30 s in duration and all of the tasks were performed each cycle. The torso flexion ranged from 5° to 16° and the peak hand force was 29.4 N. The peak shear force at L4/L5 was 118 N and the cumulative moment was 1.0 MN.m.s. Job B consisted of 14 tasks ranging from 2–16 s in duration. The potential vehicle options available at this work station meant that not every task was performed each cycle. The torso flexion ranged from 5° to 65° and the peak hand force was 50.0 N. The peak shear force at L4/L5 was 362 N and the cumulative moment was 1.48 MN.m.s.

The postures associated with the peak hand forces and shear forces are shown in figure 2. The hand forces, shear forces and cumulative moments for each of the tasks in both jobs are summarized in table 1.

3.2. *Risk analysis*

3.2.1. *Without job rotation*: Analysis by the LBPR approach of a worker at Job A for 100% of the shift produced a Combined LBPRI score of 0.46 (figure 3). For someone who worked entirely at Job B, the Combined LBPRI score was 0.81 (figure 3). The larger Combined LBPRI score for Job B is due to the greater peak hand force, peak shear force and cumulative moment associated with this job B (table 2). For each job, the TWA approach produces the same Combined LBPRI score because no job rotation is taking place. For the simple two job system, the total system risk for reporting low back pain, 1.27 (table 3) is obtained by summing the risk estimates for job.

3.3. *Risk analysis*

3.3.1. *With job rotation*: For each of the ten job rotation schedules studied the LBPR approach always produced a greater estimate for reporting LBP than the TWA approach (figure 3). The differences decreased as the amount of time working on Job B increased. Evenly dividing a worker's time between the two jobs with a 50–50 rotation produced a TWA score of 0.635 [0.46*0.5 + 0.81*0.5], a 39% relative increase in risk compared to that for working only at Job A. The LBPR approach produced an index score of 0.72, a 57% relative increase in the risk of reporting low

Table 1. The hand force, shear force at L4/L5 and cumulative moment at L4/L5 for each of the tasks for Jobs A and B.

Job	Task (no)	Number of Actions	Task Duration (s)	Repetitions (no)	Peak Hand Force (N)	Peak Shear Force (N)	Cumulative Moment[a] (MN.m.s)
A	1	1	19	364	0	35	0.08
	2	1	17	364	29.4	97	0.38
	3	1	30	364	29.4	118	0.53
	4	1	1	364	0	35	0.01
B	1	1	5	364	0	35	0.02
	2	1	5	364	0	323	0.2
	3	1	3	364	0	315	0.11
	4	1	4	364	0	206	0.1
	5	5	15	260	50	327	0.31
	6	5	14	104	28.4	327	0.12
	7	1	4	104	0	362	0.05
	8	1	9	104	0	359	0.12
	9	1	10	104	9.8	71	0.09
	10	3	7	408	21.6	315	0.13
	11	1	2	260	21.6	297	0.05
	12	4	7	260	50	286	0.1
	13	3	6	104	28.4	286	0.02
	14	1	16	364	0	35	0.05

[a] Integrated moment of force about L4/L5 over a 7 h and 14 min shift.

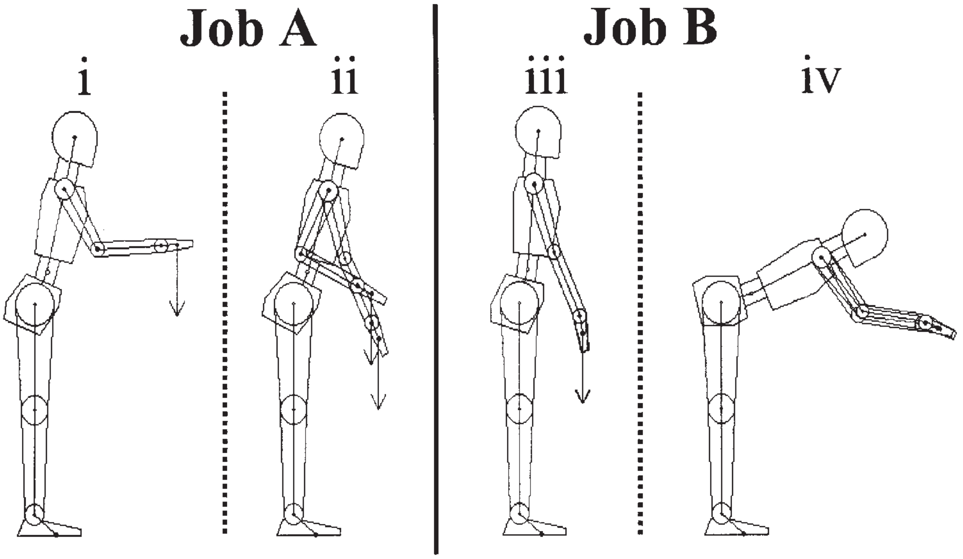

Figure 2. The postures associated with the peak hand and spine forces for Jobs A and B. For Job A, posture (i) was associated with the peak hand force (29.4 N), while posture (ii) produced the peak shear (118 N). For Job B, the peak hand force (50.0 N) was handled in posture (iii), while posture (iv), which had no forces acting on the hands, produced the peak shear (362 N).

Table 2. The input parameters used for the Low Back Pain Reporting approach to determine the Combined LBPRI score for each of the twelve rotation scenarios studied.

Time Spent Performing Each Job (% of shift)				
A	B	Peak Hand Force (N)	Peak Shear (N)	Cumulative Moment[a] (MN.m.s)
100	0	29.4	118	1
99	1	50	362	1
90	10	50	362	1.04
80	20	50	362	1.09
70	30	50	362	1.14
60	40	50	362	1.18
50	50	50	362	1.23
40	60	50	362	1.28
30	70	50	362	1.33
20	80	50	362	1.38
10	90	50	362	1.42
0	100	50	362	1.48

[a] Integrated moment of force about L4/L5 over a 7 h and 14 min shift.

back pain compared to working only at Job A (figure 3). For the worker in Job B, assessing this same rotation pattern with the TWA approach produced a relative decrease of 21% in the Combined LBPRI score, but when assessed using the LBPR method the relative change was only 11% (figure 3).

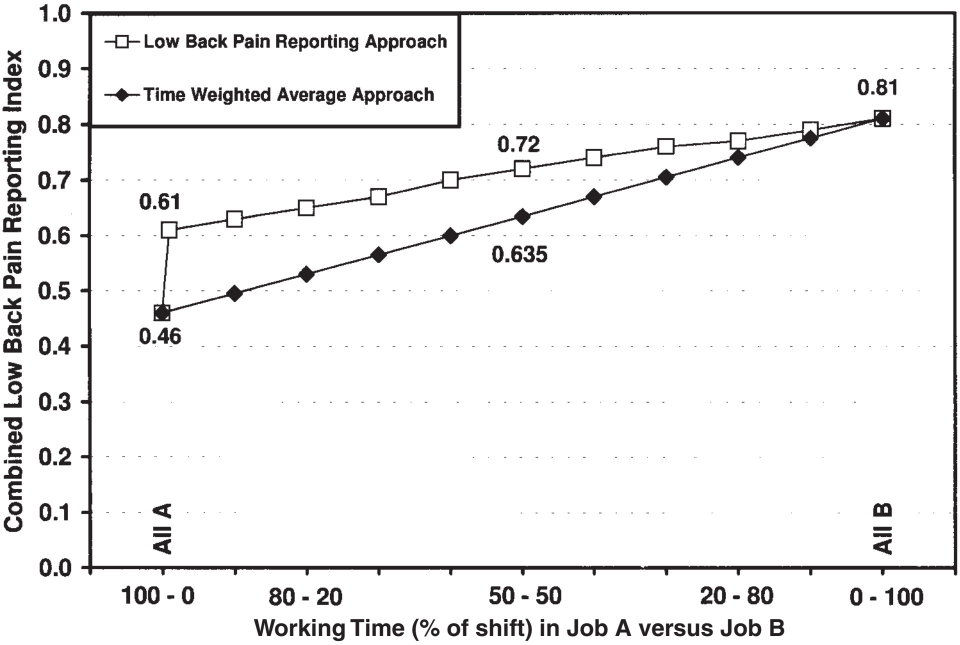

Figure 3. The Combined Low Back Pain Reporting Index (LBPRI) scores, as a result of job rotation, estimated using the Time Weighted Average (TWA) and the Low Back Pain Reporting (LBPR) approaches for different combinations of working times on Jobs A and B. Note: There appears to be only eleven symbols for the TWA approach because the 99-1 schedule produces the same risk estimate, 0.46, as the 100-0 schedule.

The largest difference between the two approaches occurred when a worker was required to spend 99% of their time on Job A and only 1% of their time on Job B (figure 3). In this scenario the TWA estimate remained unchanged at 0.46, but with the LBPR approach the Combined LBPRI score went from 0.46 to 0.61, a relative increase of 33%. This increase in Combined LBPRI occurs because the worker in Job A has now been exposed to the larger peak hand force and shear force at L4/L5 which occur as a result of the demands in Job B (table 2). However, the 1% exposure to Job B in this rotation scenario was not enough to alter the magnitude of the cumulative loading (table 2).

In absolute terms the effect of job rotation, as measured by the TWA approach, appears to be risk neutral as the system level risk for all of the rotation schedules was 1.27 (table 3). With the LBPR approach, the various job rotation schedules increased the system risk by 0.24–0.27 (table 3). The 50–50 job rotation produced the largest system risk of 1.44 out of a possible maximum of 2.0, an increase of 13% compared to the no rotation scenario.

4. Discussion

4.1. *Limitations*

The TWA and LBPR approaches resulted in substantially different estimates for the biomechanically related risk of reporting low back pain associated with job rotation. However, there are a number of limitations to the study. The first is that the two jobs

Table 3. The Combined LBPRI scores, as estimated by the Time Weighted Average (TWA) and Low Back Pain Reporting (LBPR) approaches, for each worker, for each of the rotation scenarios.

Working Time in Primary Job (% of shift)		100	99	90	80	70	60	50
Working Time in Secondary Job (% of shift)		0	1	10	20	30	40	50
TWA Approach	Worker – Job A	0.46	0.46	0.5	0.53	0.57	0.6	0.64
	Worker – Job B	0.81	0.81	0.78	0.74	0.71	0.67	0.64
	Total	1.27	1.27	1.27	1.27	1.27	1.27	1.27
LBPR Approach	Worker – Job A	0.46	0.61	0.63	0.65	0.67	0.7	0.72
	Worker – Job B	0.81	0.8	0.79	0.77	0.76	0.74	0.72
	Total	1.27	1.41	1.42	1.42	1.43	1.43	1.44

selected for analysis do not truly follow the general principle of job rotation by alleviating the fatigue and stress for a particular set of muscles. The low back musculature was involved in the performance of both jobs, although to a much smaller degree in Job A. This reflects the challenge of finding work in a production environment in which the lumbar spine is not involved in the performance of even the simplest appearing task. However, not all rotation schedules are established with this general principle in mind. In some companies the practice of job rotation is a part of their corporate culture and is utilized to enhance flexibility and productivity, to support the continuous improvement process and to foster innovation (Freiboth *et al*. 1997, Cosgel and Miceli 1999). The results of the present study may be very applicable for those who use job rotation for these purposes.

The epidemiological results of Norman *et al*. (1998) are based upon a case control study. The dose/response curve produced by the multiple logistic regression equation is strongly monotonous in nature, that is the higher the dose the higher the response (reporting of low back pain). However, too low a loading level may also be problematic. Videman *et al*. (1990) reported that histories of sedentary or heavy work each contributed more to the development of pathological findings (e.g. disc degeneration, end plate defects) in cadaveric spines than work involving mixed degrees of heaviness. This J-shape relationship appeared for several variables (e.g. disc degeneration, end plate defects). It appears that too little, or too much, loading may be problematic and that perhaps there is an optimum level of loading which would minimize risk of injury. If this is the case, job rotation may indeed be beneficial because for a worker in an extremely sedentary job an increase in their activity level may decrease their injury risk, while decreasing exposure time for a worker in a more demanding job might decrease their level of risk. If this optimal loading model is correct then the LBPR approach may not be correctly accounting for the lowest levels of loading. This possibility remains only conjecture because, to the authors' knowledge, these are the only epidemiologically based dose/response curves available for the analysis of reporting low back pain.

The LBPR approach was utilized because it provides an indication of the risk for reporting low back pain associated with the work demands of a specific job. Although the Combined LBPRI score represents each job by a single number and facilitates comparison, it hides the fact that both peak and cumulative risk factors are being taken into consideration. Certainly the cumulative risk factor is averaged across jobs when rotation occurs. But, the very nature of a peak risk factor means that, between two jobs, there can only be one single value which represents the peak level of exposure. Peak values are not averaged between jobs. It is possible that using a TWA approach with the Combined LBPRI scores may not be appropriate. However, this is exactly what is done when a person is given the risk for two jobs, assumes that rotation averages out the risk, and calculates the risk for a 50 – 50 rotation scheme ([Risk A + Risk B]/2]). Using the TWA approach simply formalizes the procedure that people commonly use.

Other limitations in this study reflect the challenges which occur when collecting data in industrial environments. The analysis in this study was restricted to observing a single operator in each job due to production restrictions. Although this was sufficient for the job rotation simulations, the inclusion of additional operators would have produced variability in the postures adopted during production, resulting in variability in the Combined LBPRI score estimated for each job. While this may have altered the differences between the scores it would not have changed the general findings regarding the effects of rotation.

For the job analysis, the software required that the actions were at least 1 s in duration and that the dynamic tasks of production were represented by static postures. In the present study the shortest action was 2 s in duration and there were no rapid actions in the jobs selected for analysis. However, to protect against over/under estimates of physical loading, a posture which was representative of the entire action was selected for any of the dynamic tasks. Because it was not possible to measure all the forces acting on the hands, the peak and cumulative loading parameters may be underestimated. Also, because it was not feasible to measure the support forces acting on the workers the peak spinal shear forces and cumulative moments may be overestimates. This may cause the Combined LBPRI scores to be artificially increased, especially for Job B which required the worker to lean into the vehicle.

A static analysis was performed because it was not possible to measure dynamic hand forces in this environment. If these had been available they could have been entered into the model and a quasi-dynamic analysis would have been performed. A two dimensional analysis was selected because the jobs required very little twisting and for most of the tasks it was possible to video the torso in the sagittal plane. Although a three dimensional analysis of the jobs may have produced more accurate spinal loading estimates, it was expected that any over or under estimates would be uniformly distributed and not severely affect the risk estimates or the comparisons. The estimates of L4/L5 compression, shear and moment are dependent upon the validity of the model used to make them. Direct validation of each of these variables via *in vivo* measurements of the same variables, in the same units, is currently not possible. Therefore, the anatomical and physiological content validity of the model are important. The biomechanical model used in this study has attempted to incorporate as much content validity as possible in an industrially usable version.

4.2. *Effects of job rotation*

In spite of the limitations discussed above, the implementation of job rotation produced substantially different predictions for the risk of reporting low back pain when estimated using the TWA approach compared to the LBPR approach. With job rotation, the redistribution of the risk was linear for the TWA approach and non linear for the LBPR approach. The total amount of risk present between the two workers did not change for the TWA approach while the LBPR approach produced a net increase due to the increases in peak loading. With the LBPR approach, the worker rotating out of the more demanding job experienced a decrease in risk, but the worker rotating into this job sustained a much greater increase in risk, negating any advantage at the system level.

The net increase in risk for the LBPR approach occurs because combining tasks affects both peak and cumulative tissue loading exposure. For the worker in Job B, rotating to Job A reduces only one of the three risk factors. The cumulative L4-L5 moment decreases but the peak hand force and shear force at L4/L5 to which the worker is exposed during their shift are not altered. The decrease in Combined LBPRI score reflects the decreased cumulative load. For the worker in Job A who rotates to Job B, all three risk factors increase due to working at the more demanding job. With job rotation, the two workers have experienced a net increase in two risk factors and the LBPR approach reflects this. These findings support the observation of Keyserling *et al.* (1991) who indicated that job rotation by itself only changes the cumulative daily exposure but does not alter other generic risk factors (e.g. awkward postures, repetition) to which a worker is exposed. While a job rotation strategy might evenly distribute cumulative loading, raising it for some workers, lowering it for others, it also exposes all workers involved in the rotation schedule to the highest peak load, increasing the predicted risk for everyone rotating into that job.

In contrast, the TWA approach is insensitive to the specific work demands because it assumes that all risk factors change proportionally with time and are spread out evenly. In general, combining tasks via job rotation may influence both peak and cumulative tissue loading and predictions of the effects of job rotation on injury risk that are based on an even redistribution assumption should be held with some skepticism.

Kuijer *et al.* (1999) evaluated the effects of job rotation in a refuse collecting department. Workers who rotated between refuse collecting and street sweeping were compared to a non-rotating group for each job. On average, those who rotated had significantly lower levels of perceived effort and fatigue, spent less time with their trunk inclined past 45° to the vertical and used a smaller percentage of their heart rate reserve compared to refuse collectors who did not rotate. However, it appears that these two groups performed different amounts of work. The rotating workers' daily average of 572 (± 208) refuse bags handled was only slightly more than one-third of the 1556 (± 229) bags handled by the non-rotating collectors. The authors attributed the source of this difference not to less refuse being placed on the street for pick up by the rotation group, but rather to a technical limitation in that only one worker per day could be observed. They credit the non-observed partner with doing more than their share of work. This might explain the favourable psychophysical and physical results regarding rotation. However, the difference in work loads makes it difficult to determine how effective the rotation would truly be if the work loads were the same for each group. This work illustrates how challenging it can be to evaluate interventions in field settings. It also underscores the necessity for having the production volume, or the physical exposure, as similar as possible between the intervention and control groups when evaluating interventions such as job rotation. The simulation used in this study allows that to be done.

In efforts to improve competitiveness and profitability, job rotation may be adopted by even more companies. However, as the work force ages, this strategy may become problematic. Spinal compression tissue tolerance decreases with age (Jager *et al.* 1991). Also, Gaudart (2000) found that, in the French automobile industry, older workers performed less job rotation. Ageing operators 'posted out of', or avoided work situations that were damaging to their health, and/or did not allow their organizational skills and strategies to be utilized successfully. Technological and organizational changes which increase task complexity, such as job rotation, may occur at the same time as the abilities of the workforce are decreasing. This combination of factors may require careful consideration for implementing job rotation in future work design.

Ideally, risk of injury should be reduced to zero. However, it would be appear that risk of low back pain is present even in sedentary jobs (Videman *et al.* 1990). The LBPR approach presented in this paper would appear to identify some of this risk for it estimates that a 50th percentile male who simply stands all day long would have a combined LBPRI score of 0.13. In designing work, and work schedules, the effects of both peak and cumulative loading need to be considered. As an administrative control, job rotation may not be as effective at reducing biomechanical injury risk factors as expected. This emphasizes the importance of engineering controls because they help to diminish the exposure in the system and therefore provide a benefit to all workers required to perform that job. Reducing high peak forces, or heavy work, is important. However, designing the heavy work out of jobs, although necessary, is not sufficient to reduce risk. High levels of cumulative forces can arise from performing many repetitions of work and/or working for prolonged durations with low levels of peak forces and these latter situations must not be overlooked. By reducing high forces that are repeated or prolonged, a beneficial effect is produced in reducing both peak and cumulative risk factors.

The results of this study are especially important given the popularity of citing job rotations as a risk reduction mechanism (Jonsson 1988, Vander Doelen and Barsky 1990, Hazard *et al.* 1992, Wands and Yassi 1993, Grant *et al.* 1997, Kuijer *et al.* 1999). Although many advantages have been attributed to job rotation (Triggs and King 2000), its effects on injury risk should be carefully examined when determining whether job rotation is to be implemented. However, in the absence of clear exposure standards or limits, it is difficult to know how effective a strategy job rotation may be (Stoffman and Sykes 1999).

Finally, although only an example, this paper demonstrates that rotation may not reduce injury risk as much as expected and that it may increase the risk for some. The authors suggest that this finding may be applicable in other jobs and rotation schemes used in industry. Further research is still needed on the effects of job rotation/enlargement on exposure health effects and performance.

5. Conclusions

The use of the time weighted average approach (TWA) for estimating the effects of job rotation on the probability of reporting low back pain may not be appropriate with scores that involve both peak and cumulative risk factors.

As soon as a worker in a low demand job rotates into a high demand job, a step increase occurs in the probability of reporting low back pain because of the immediate exposure to the peak loading parameters associated with the more demanding job.

In the simulation performed, the redistribution of risk was not uniform with job rotation. The increase in risk was greater for those who rotated into the demanding job than the reduction experienced by those who rotated out of the demanding job.

Reducing high peak forces, by designing the heavy work out of jobs, is necessary but not sufficient to reduce high peak and cumulative risk factors. High cumulative forces (a high risk factor) can arise from high repetitions or prolonged work that involves only low peak forces. Both the amplitude and duration of loading must be considered when trying to reduce risk. Reducing high forces that are repeated, or prolonged, has a beneficial effect on reducing both types of risk factor.

Acknowledgements

This study was supported by the Canadian Auto Workers, General Motors of Canada Limited, The Woodbridge Group, A.G. Simpson, and HEAL*Net*. The case control study which produced the epidemiological database was funded entirely by the Institute for Work and Health which receives its core funding from the Workplace Safety and Insurance Board of Ontario.

References

Adams, M. A. and Hutton, W. C. 1985, Gradual disc prolapse, *Spine*, **15,** 311–316.

Andrews, D. M., Norman, R., Wells, R. and Neumann, P. 1997, The accuracy of self-report and trained observer methods for obtaining estimates of peak load information during industrial work, *International Journal of Industrial Ergonomics*, **19,** 445–455.

Cosgel, M. M. and Miceli, T. J. 1999, Job rotation: cost, benefits and stylized facts, *Journal of Institutional and Theoretical Economics*, **155,** 301–320.

FASC 1986, *Canadian Standardised Test of Fitness Operations Manual,* 3rd ed. (Ottawa: Fitness and Amateur Sport Canada).

Freiboth, M., Frieling, E., Henniges, D. and Saager, C. 1997, Comparison of different organisations of assembly work in the European automotive industry, *International Journal of Industrial Ergonomics*, **20,** 357–370.

Gaudart, C. 2000, Conditions for maintaining ageing operators at work – a case study conducted at an automobile manufacturing plant, *Applied Ergonomics*, **31,** 453–462.

Grant, K. A., Habes, D. J. and Bertsche, P. K. 1997, Lifting hazards at a cabinet manufacturing company: evaluation and recommended controls, *Applied Occupational and Environmental Hygiene*, **12,** 253–258.

Hansson, T. H., Keller, T. S. and Spengler, D. M. 1987, Mechanical behaviour of the human lumbar spine. II. Fatigue, strength during dynamic compressive loading, *Journal of Orthopaedic Research*, **5,** 479–487.

Hazard, L., Mautz, J. and Wrightsman, D. 1992, Job rotation cuts cumulative trauma cases, *Personnel Journal*, **71,** 29–32.

Henderson, C. J. 1992, Ergonomic job rotation in poultry processing, in S. Kumar (ed.), *Advances in Industrial Ergonomics and Safety IV* (London: Taylor & Francis), 443–450.

Jager, M., Luttmann, A. and Laurig, W. 1991, Lumbar load during one-handed brick laying, *International Journal of Industrial Ergonomics*, **8,** 261–277.

Jonsson, B. 1988, Electromyographic studies of job rotation, *Scandinavian Journal of Work Environment and Health*, **14(suppl.),** 108–109.

Kerr, M. S., Frank, J. W., Shannon, H. S., Norman, R. W. K., Wells, R. P., Neumann, W. P. and Bombardier, C. and the Ontario Universities Back Pain Study Group 2001, Biomechanical and psychosocial risk factors for low back pain at work, *American Journal of Public Health*, **91,** 1069–1075.

Keyserling, W. M., Armstrong, T. J. and Punnett, L. 1991, Ergonomic job analysis: a structured approach for identifying risk factors associated with overexertion injuries and disorders, *Applied Occupational and Environmental Hygiene*, **6,** 353–363.

Kuijer, P. P. F. M., Visser, B. and Kemper, H. C. G. 1999, Job rotation as a factor in reducing physical workload at a refuse collecting department, *Ergonomics*, **42,** 1167–1178.

NORMAN, R. and WELLS, R. 2000, Ergonomic interventions for reducing musculoskeletal disorders, in T. Sullivan (ed.), *Injury and the New World of Work* (Vancouver, BC: UBC Press), 115–139.

NORMAN, R., WELLS, R., NEUMANN, P., FRANK, J., SHANNON, H. and KERR, M. and the ONTARIO UNIVERSITIES BACK PAIN STUDY (OUBPS) GROUP 1998, A comparison of peak versus cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry, *Clinical Biomechanics*, **13,** 561–573.

PUTZ-ANDERSON, V. 1988, *Cumulative trauma disorders: a manual for musculoskeletal diseases of the upper limbs*, (London: Taylor & Francis).

SMITH, T. J., HAMMOND, S. K., HALLOCK, M. and WOSKIE, S. R. 1991, Exposure assessment for epidemiology: characteristics of exposure, *Applied Occupational and Environmental Hygiene*, **6,** 441–447.

STOFFMAN, L. and SYKES, M. 1999, Job rotation and compliance with the B.C. ergonomic regulatory requirements, in *Ergonomics and Safety. Proceedings of the 31st Annual Conference of the Association of Canadian Ergonomists* (October 13–16, Hull: Quebec), 175–180.

TRIGGS, D. D. and KING, P. M. 2000, Job rotation: an administrative strategy for hazard control, *Professional Safety*, **45,** 32–34.

U.S. DEPARTMENT OF LABOUR 1993, *Ergonomics program management guidelines for meatpacking plants* (Occupational Safety and Health Administration Publication No. 3123, Occupational Safety and Health Administration, Washington, D.C).

VANDER DOELEN, J. A. and BARSKY, S. J. 1990, Repetitive strain injury within the meat-processing industry, *Occupational Health in Ontario*, **11,** 154–167.

VAN VELZER, C. T. 1992, Economic ergonomic interventions: The benefits of job rotation, *Proceedings of the 25th Annual Conference of the Human Factors Association of Canada* (October 25–28, Hamilton: Ontario), 207–212.

VIDEMAN, T., NURMINEN, M. and TROUP, J. D. G. 1990, Lumbar spinal pathology in cadaveric material in relation to history of back pain, occupation, and physical loading, *Spine*, **15,** 728–740.

WANDS, S. E. and YASSI, A. 1993, Modernization of a laundry processing plant: is it really an improvement?, *Applied Ergonomics*, **24,** 387–396.

WELLS, R. P., KEIR, P. J. and MOORE, A. E. 1995, Applications of biomechanical hand and wrist models to work-related musculoskeletal disorders of the upper extremity, in S. L. Gordon, S. J. Blair and L. J. Fine (eds), *Repetitive Motion Disorders of the Upper Extremity* (Rosemont, IL: American Academy of Orthopaedic Surgeons), 111–121.