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The Relationships Between Biomechanical and Postural Stresses, Musculoskeletal Injury Rates, and Perceived Body Discomfort Experienced by Industrial Workers: A Field Study

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A combination of archival, subjective, and observational field data collection methods were used to investigate the relationship between biomechanical and postural stresses, and the resulting physical strain experienced by industrial workers of a packaging plant. Assessment of physical strain was based on the number and incidence rate of Occupational Safety and Health Administration (OSHA)-reportable injuries that were recorded over a period of 27 months, and based on the self-reported ratings of perceived body discomfort. Both the biomechanical and postural stresses correlated with the musculoskeletal injury rate. The results illustrate the usefulness of postural and biomechanical analyses for assessing the risk of injury in industry.

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musculoskeletal injury ergonomics postural stress
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1. INTRODUCTION

Historically, the basic approach to accident prevention, and thus injury prevention, focused on unsafe acts related to worker behavior (Purswell & Rumar, 1984). As such, countermeasures were directed toward better training, education, and motivation for workers. Later, worker selection and placement approaches were advocated. Likewise traditional measures of safety performance have focused on outcomes—injury frequency and severity. These approaches have had limited long-term value in controlling injuries and associated costs. More effective techniques can be developed using an ergonomic approach, which considers specific job characteristics demonstrated to be related to frequency and severity of injury (Karwowski & Marras, 1999). Successful techniques will enable an assessment of risk before injuries occur. Such techniques allow to take preventive actions, and, therefore avoid unnecessary costs and human suffering (Karwowski, Wogalter, & Dempsey, 1997).

This study investigated the relationship between two ergonomic risk factors, posture and force, and the resulting physical strain among a selected group of industrial workers. The study was carried out as field research in cooperation with the management and workers of a paperboard packaging plant located in the eastern part of the USA. The main objective of the analysis focused on examining correlations between measures of postural and biomechanical stress and measures of strain. Physical stress, due to imposed job demands, and the resulting physical strain experienced by workers was determined as follows. Strain was based on the number and incidence rate of injuries and self-reported ratings of perceived discomfort, whereas stress was estimated from postural and biomechanical analyses.

2. METHODS AND PROCEDURES

Research activity was carried out in one plant in the folding carton group of a multi-plant packaging division of a Fortune 500 corporation manufacturing consumer products, food packaging, and communications paper. The plant

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produces a large variety of folding cartons used in retail packaging for food and other consumer products that have high-volume distribution. Typical products are ice cream, bakery, and candy cartons; cereal and frozen food boxes; and packaging for pharmaceuticals and toiletries.

A brief description of the manufacturing process is provided as a frame of reference for work activities carried out at the plant (the reader is referred to Hanlon [1992] for a more detailed description). The primary steps in manufacturing folding cartons are printing paperboard raw stock, cutting carton patterns from the printed stock and placing crease lines for folding, and finishing operations. The major plant departments, press room, cut and crease, and finishing correspond to these steps. A number of secondary operations support these activities. Customer requirements ultimately determine which specific manufacturing operations are needed for a given product.

Paperboard is received as sheet or roll stock. Roll stock must be processed through the sheeting operation to be cut into individual sheets. Most customers order printed cartons, so the majority of sheeted stock goes through the printing operation. However, some cartons, frozen foods, for example, are not printed and sheet stock moves directly to cutting. Several offset rotary presses, which vary in the number of printing units, are used for printing. Because a number of different cartons may be printed on each sheet, production runs are assembled according to a sheet layout. Once sheets have been printed, cartons for different customers and products must be cut, separated, and kept apart for further processing. A cutting and creasing die is used to cut and score individual cartons according to the layout pattern. Cut sheets are then stripped. The stripping operation removes trim from sheet edges and between the cartons. Several cutting presses are equipped to machine strip, however, production volume and unsuitable layout patterns necessitate manual stripping for a large percentage of the plant’s production. Products for some customers require no further processing and are prepared for shipping. The remaining products are moved on to finishing operations.

The plant offers three types of finishing operations: (a) wax coating, (b) cellophane inserts, and (c) side-seam gluing. These operations are performed on separate production lines. Wax coatings are applied to cartons on several wax lines. Cellophane film inserts, such as the “see-through window” on bakery cartons or the “flavor seal” on ice cream boxes, are affixed to cartons on the cellophane lines. Carton side-seams are glued on straight-line gluers. Cartons may be processed on multiple lines. After processing, cartons are packed into corrugated fiberboard boxes for shipping.

2.1. Physical Strain Assessment

Physical strain analysis is concerned with the worker's physical and mental response to imposed job demands, which are manifested by discomfort, fatigue, or injury (Kee & Karwowski, 2001). Thus, strain may be viewed as the worker's response to job stresses (Parrot, 1973). Typically, the medical, safety, and cost records can be reviewed and workers surveyed about the perceived problems (Anderson, Fine, Herrin, & Sugano, 1985; Burke, 1992; Karwowski & Marras, 1999; Ortiz & Gleaves, 1991; Putz-Anderson, 1988).

In this study, an assessment of physical strain was made using two data sources. First, archival data concerning injury frequency and severity were examined. Second, subjective data were collected from workers concerning past history of musculoskeletal trouble and the level of discomfort experienced while performing work activities. These data sets were used to compute statistics of injury, point prevalence of musculoskeletal disorders, and worker discomfort profiles. Analysis results were used to identify job classifications, which demonstrated high risk of musculoskeletal injuries, disorders, or discomfort.

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Medical and safety records were reviewed as the first step toward the identification of high cost work activities or operations. Data collection software was written to efficiently transfer archival data, stored in the form of accident reports, into an electronic database to facilitate subsequent analyses. The software was written to operate under Microsoft Windows® using Borland's Object Vision®. Over 800 incident reports, events that generated an accident report, were entered for the period of 27 months. Recordable and lost time injuries were identified from Occupational Safety and Health Administration (OSHA) 200 logs. Medical, indemnity, and expense cost data related to workers' compensation were obtained from claim detail reports, generated by the insurance plan administrator.

Injury statistics were computed on the basis of the number of recordable cases, number of lost workdays, cost of injuries, number of employees, and total employee hours. The number and percentage of injury incidents were tabulated and totaled for the plant by individual job classifications. Incidence and loss rates were computed for selected jobs. Illness data, with the exception of repetitive motion disorders, were omitted from the analysis. The following rates were calculated: incident report rate, recordable incident rate, lost workday cases rate with restricted days, number of lost workdays rate, and net claim loss rate.

Two surveys, administered over a 2-week period, were used to quantify workers' perceived discomfort level. The Musculoskeletal Discomfort Survey

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measured the magnitude of perceived discomfort for 11 parts of the body: neck, upper back, low back, shoulder, elbow, wrist/hand, fingers, hip/thigh, knee, ankle/foot, and toes. A 10-point rating scale ranging from *no discomfort* to *extreme discomfort* was used. The survey was administered at the start, after 4, 8, and 12 hrs of the shift. The Musculoskeletal History Survey was used to make an assessment of the workers' prior history with respect to musculoskeletal "trouble." This survey was derived from the Nordic questionnaires (Kuorinka et al., 1987).

One hundred and ten workers were randomly selected by job classification to participate in the musculoskeletal history and discomfort surveys. Each worker received a 15-min orientation session the day before the surveys started. During the session, each worker was given one discomfort survey booklet to be completed each week and one history survey to be completed at any time over the 2-week period. The completed survey data were entered in a computer database and analyzed to determine discomfort rating profiles for each of the surveyed jobs. Twelve job classifications were ranked in terms of relative risk and compared to the rankings based on injury data.

2.2. Physical Stress Assessment

Results from the physical strain assessment were used to identify higher risk job classifications for more detailed physical stress analysis. The four job classifications were selected and observed to collect data for physical stress assessment. These job classifications were as follows: press operator, carton stripper, glue line operator, and glue line quality production associates (QPAs). For each job classification observed, job activities were identified and documented. The job descriptions, which follow, were supplemented with workstation diagrams and job task flowcharts.

2.2.1. Description of jobs

The press operator is the lead person of a three-person crew, which is responsible for all aspects of production on one press. Work activities may be broadly divided into press make-ready and run-time tasks. Make-ready entails a variety of setup activities to prepare the press for printing each new layout pattern. Included are tasks such as installing new printing plates, washing blankets, cleaning cylinders, filling the ink reservoirs, setting ink flow, and other press adjustments to ensure color accuracy and print registration. Run-time activity centers on constantly monitoring press operation, using a number of visual and quality control procedures, to maintain high quality printing. In addition to quality checks, pallets of printed sheets are removed from the discharge area to the trucking right of way. Periodically the press crew performs cylinder changes, removing worn cylinders and installing refinished or new cylinders.

The carton stripper separates trim from the edges of the cut sheets and from between cartons. This operation also separates and repels individual cartons from the cut sheets for finishing operations or shipping. Cartons and trim are separated by breaking the nicks, which hold the cut sheet together. A hand hammer or air hammer is used for this process. Cut sheets are delivered to the stripping workstation on pallets. A pallet is about 91 cm high and holds between 1,000 and 2,000 cut sheets. The stripper first uses a hand hammer to break the nicks on the top layers. An air hammer is then pushed down through the stack of sheets to separate the lower layers. The stripper works around the pallet starting with the edge trim and then separating carton stacks. Once a stack of cartons is separated, it is re-piled on a pallet for finishing or into shipping cases. Trim is swept into a vacuum chute and conveyed to a separate area where it is baled for recycling. Strippers also spend a portion of the day as relief operators on the cutting presses.

Each side-seam gluer in finishing is staffed by a three-person crew. The operator loads cartons into the in-feed magazine of the machine. Cartons are transferred from pallets located behind and at the side of the operator. Cartons may be transferred directly from the pallets to the magazine or larger stacks may be transferred to a worktable and then loaded. Two QPAs "catch and pack" the completed cartons. The QPAs rotate between two workstations each half hour. At the first station, the QPA gathers cartons from the discharge conveyor and packs them into corrugated shipping cases. The cases are manually palletized at the second station.

2.2.2. *Videotape work sampling procedure*

Observation data were collected using a work sampling design, one of several techniques commonly used to measure work activity (Shell, 1986). The study was designed to attain a 95% level of confidence for activities or elements occurring approximately 10% of the time with a precision of ±5%. A sample in this study was a 10-s segment of videotape recording work activity or delay. Supplemental data needed for input to the biomechanical model or observer comments were noted on a separate form. Likewise, if the worker was absent from the workstation when an observation was scheduled, it was noted on the supplemental data sheet. One worker from each job

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classification was videotaped for one 8-hr shift. The particular worker was a volunteer who represented a median level of performance within the classification as determined by the area supervisor. Samples were collected at 2-min intervals throughout the shift, following a systematic random sampling procedure. In general, the participant was centered, head to feet, in the frame and filmed from the front and behind at a 45° angle. Prior to videotaping, the purpose and procedure was explained to each worker.

2.2.3. Postural stress

TABLE 1. Posture Classification by Job Title

Body Region	Classification	Press Operator	Carton Stripper	Glue Line Operator	Glue Line QPA
NECK	Neutral	31	32	37	41
	Flexion 16–45°	27	20	37	13
	Flexion >45°	3	0	1	0
	Extension >15°	5	28	2	8
	Lateral bending >15°	7	16	2	2
	Rotation >15°	45	26	28	43
BACK	Neutral	58	41	50	43
	Flexion >15°	12	48	22	17
	Extension >15°	1	1	0	0
	Lateral bending >15°	10	10	5	5
	Rotation >15°	28	19	29	46
SHOULDER	Neutral	59/52	28/43	38/45	41/43
left/right side	Anterior elevation 16–45°	12/20	29/28	54/44	36/29
	Anterior elevation >45°	16/20	36/28	8/6	21/19
	Posterior elevation 16–45°	12/6	2/1	1/4	2/7
	Posterior elevation >45°	1/2	4/0	0/0	1/2
ELBOW	Neutral	68/64	62/58	90/88	76/78
left/right side	Flexion >120°	1/1	5/1	1/0	0/1
	Extension <60°	29/32	29/41	9/12	24/21
	Pronation >15°	1/1	3/3	0/0	0/1
	Supination >15°	3/2	1/2	0/0	0/0
WRIST	Neutral	71/69	51/68	62/66	63/70
left/right side	Flexion 16–45°	4/2	10/1	5/5	2/4
	Flexion >45°	1/1	0/0	2/1	0/0
	Extension 16–45°	11/14	19/14	10/9	22/11
	Extension >45°	2/3	6/5	1/1	2/1
	Radial deviation	2/2	2/3	5/4	6/4
	Ulnar deviation	12/13	22/15	20/17	10/16
FINGER	Neutral	69/45	37/48	55/54	70/65
left/right side	Pinch	25/39	47/35	40/41	21/27
	Power	6/16	16/17	5/5	9/8

Notes. QPA—quality production associate.

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An observation-based postural stress analysis technique, which entails observing workers either directly in the workplace or viewing videotape recordings of work activity, was used in this research. Posture categories for the neck, back, shoulder, elbow, wrist, and fingers were chosen based on a review of the literature, so that postural stress could be rapidly classified with a minimum number of standard categories in a manner sufficient to document angular deviations often associated with musculoskeletal disorders (Genaidy, Al-Shedi, & Karwowski, 1994), see Table 1.

Observation data were recorded by reviewing the videotapes of work activity for each job classification. The videotapes consisted of alternating segments of work activity and “fades to black.” The latter, referred to here as fade segments, were used to separate observations. A specific frame was selected for analysis by advancing the tape forward through the fade segment to a point just prior to the start of the work activity segment. The tape was then advanced one frame at a time until the first frame of work activity was displayed. A freeze frame feature was used to maintain the image on the monitor. Postures were observed and recorded on a data sheet. One data sheet was used for each observation. Task descriptions and joint angles for the biomechanical analysis were recorded at the same time. The coded data were entered into an electronic database. Output results were presented as the percentage of time spent in each posture category.

2.2.4. Cumulative biomechanical stress

Biomechanical analysis is generally limited to a particular posture or task deemed critical to the job being analyzed. Workers are considered to be at greater risk of musculoskeletal injuries if estimated forces and torques exceed tissue biomechanical tolerance limits of either an individual or a certain percentage of the working population (Genaidy, Waly, Khalil, & Hildago, 1993). The analysis is carried out to estimate the maximum compressive or shear force occurring during the job, for example during lifting. However, epidemiological studies indicate that low back pain is often attributed to the deterioration of intervertebral discs, facet joints, and ligaments of the spine due to biomechanical wear and tear (Andersson, 1981; Edgar, 1979; Frymoyer et al., 1983). A distinction may be made, therefore, between biomechanical stresses which result in (a) instantaneous traumatogenesis, such as a fracture or dislocation, and (b) cumulative pathogenesis, which describes the gradual development of disability or disease through repeated exposure over extended periods of time (Tichauer, 1978).

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Cumulative biomechanical stress analysis is an application of biomechanical analysis throughout the work cycle or work shift for the purpose of estimating workload. Hence, cumulative biomechanical analysis attempts to measure changes in the magnitude of biomechanical stress in a manner that more accurately represents variations in work activity.

Despite considerable for estimating of the peak forces, the application of biomechanics to quantify cumulative load has been largely ignored. Two techniques have been reported using cumulative biomechanical analysis. Keyserling, Fine, and Punnett (1987) presented the following equation as an extension of a postural analysis of trunk flexion and noted the need for further research.

$$CSC = \sum_{i=1}^{n} T_i \times SC_i, \tag{1}$$

where

CSC — cumulative spinal compression (N-s),
T_i — time spent in posture i (s),
SC_i — spinal compression in posture i (N),
n — number of different posture classification categories.

Kumar (1990) used a structured questionnaire-interview method to identify stressful tasks and determine critical working postures, forces, and their frequency in a study of 161 institutions. The cumulative daily load, compressive or shear, was calculated as follows:

$$CDC_O = \sum_{i=1}^{n} (MC_{Oi} \times F_i), \tag{2}$$

where

CDC_O — cumulative daily overall compression for tasks i to n (N·s),
MC_{Oi} — spinal compression from load M for task i (N),
F_i — frequency per day for task i (s),
n — number of different tasks performed.

Cumulative weekly, monthly, and yearly loads were calculated from cumulative daily load on the basis of 5 days per week, 4 weeks per month, and 12 months per year. In this way, force loading was quantified over the entire work experience. Participants were divided into two groups, one group reporting "pain" and the other reporting "no-pain" in the structured questionnaire-interview session. The cumulative compressive load, calculated for participant's current job, was found to be significantly higher for the pain group compared to the no-pain group. Thus, it was concluded that the observations clearly suggest that cumulative load exposure predisposed the spine to pain and injury and is, therefore, a risk factor.

For this research compressive and shear stresses were estimated from biomechanical analysis. Reactive compressive and shear forces were determined from a biomechanical analysis using a model developed by the University of Miami (1986). In addition, the compressive force for each observation was compared to the damage load (Genaidy et al., 1993). Data from the coding sheets, force, and joint angles, were entered into the biomechanical model. The resulting compressive force estimates for each observation were entered into an electronic spreadsheet and totaled to compute the cumulative biomechanical stress. Thus, cumulative load was calculated for the 8-hr workshift as shown in Equation 3:

$$CBL = \sum_{i=1}^{n} C_i, \tag{3}$$

where

CBL — cumulative spinal compression (N per 8 hrs),
C_i — spinal compression for observation i (N),
n — number of work sampling observations.

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3. RESULTS

3.1. Injury Statistics

The following job classifications were found to have the greatest number and percentage of incidents: cut and crease operator, finishing QPA, maintenance mechanic, carton stripping, and press operator. Carton stripping, finishing QPA, and press operator were ranked highest for recordable incident rate, lost workday cases rate with restricted days, and number of lost workdays rate. Carton stripping, finishing QPA, press operator, and finishing operator ranked highest for net claim cost rate.

3.2. Musculoskeletal Surveys

Orientation sessions to discuss the survey were well attended. Eighty-four percent of the employees who were selected to participate attended. Adjusted for absences and employees not reporting to work this was a 91% attendance rate. Exactly half, 55, of the original 110 employees returned completed survey booklets. Actual participation by job classification ranged from 11 to 100% of the selected employees. Thus, respondents represented 11 to 75% of the employees in a particular job classification.

Responses to the Musculoskeletal History Survey: General Survey, expressed as percentages, represent the point prevalence of self-reported musculoskeletal ache, pain, or injury for the upper extremities, spine, and lower extremities across the facility. Responses were as follows: shoulder, 48; elbow, 35; wrist, 60; fingers, 36; neck, 42; upper back, 43; low back, 65; hip, 33; knee, 35; ankle, 53; and toes, 18.

Data from the Musculoskeletal Discomfort Survey were analyzed by job classification. Individual body area scores were used to calculate four composite scores for each job classification. A composite score for each job classification is given in Table 2. The cumulative difference score, $\Sigma(T3 - T1)$, was calculated as the sum each body area's mean difference score. A range score, >5, was a count of the number of body areas which appeared in the greater than 5 range category. A grand mean, AVERAGE T(3), was calculated for each job from the mean (after 8 hrs) discomfort scores of each body area. The final score, MAX, was the maximum mean (after 8 hrs) discomfort score for all body areas.

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TABLE 2. Results Summary by Job Classification

Job Classification	I(RI)	T(3)	Σ(T3 – T1)	MAX	>5	%NNP	CBL	DAYS
Press Operator	23	0.49	3	1.63	3	44	40	428
Carton Stripper	28	0.84	8	1.84	6	55	45	486
Glue line Operator	3	1.23	9	3.38	6	44	30	258
Glue line QPA	21	0.70	6	1.77	11	47	33	699

Notes. I(RI)—recordable incident rate, T(3)—end of day grand mean, Σ(T3 – T1)—cumulative difference score, MAX—maximum mean body area score, >5—range score, %NNP—percentage of time in non-neutral postures, CBL—cumulative biomechanical loading, DAYS—number of lost workdays rate, QPA—quality production associate.

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3.3. Comparison of Injury Statistics and Survey Results

A positive relationship was anticipated between the statistics of injury and musculoskeletal discomfort scores, because these were both measures of physical strain. Furthermore, the relationship was expected to be highly correlated. To test this hypothesis, a correlation analysis was made for six injury statistics and four composite discomfort scores. Injury statistics, by job classification, included the following injury rates: incident report rate, I(N); recordable incident rate, I(RI); lost workday cases rate with restricted days, LDR; number of lost workdays rate, DAYS; and net claim loss rate, COST. The percent of injuries occurring in each job classification was also included, I(%). The discomfort surveys collected data for individual body areas. As such, an aggregate score was needed to compare job classifications. Discomfort level for each job classification was represented by four separate composite discomfort survey scores: the cumulative difference score, Σ(T3 – T1); the range score, >5; grand mean, AVERAGE T(3); and maximum mean body area score, MAX. Correlation analysis results are given in Table 3.

TABLE 3. Correlation Matrix: Incident and Survey Data

	I(N)	I(RI)	LDR	DAYS	COST	I(%)	Σ(T3 – T1)	>5	T(3)
I(N)									
I(RI)	.276								
LDR	.005	.906							
DAYS	–.083	.856	.866						
COST	–.286	.701	.716	.922					
I(%)	.558	.499	.442	.517	.413				
Σ(T3 – T1)	–.410	.240	.379	.421	.553	.085			
>5	–.430	.509	.704	.844	.854	.377	.533		
AVERAGE T(3)	–.549	–.262	–.120	–.043	.194	–.216	.850	.174	
MAX	–.176	–.314	–.270	–.104	–.080	–.202	.375	.157	.393

Notes. I(N)—incident report rate, I(RI)—recordable incident rate, LDR—lost workday cases rate with restricted days, DAYS—number of lost workdays rate, COST—net claim loss rate, I(%)—percentage of injuries, Σ(T3 – T1)—cumulative difference score, >5—range score, T(3)—end of day grand mean, AVERAGE T(3)—grand mean, MAX—maximum mean body area score.

Injury frequency was measured by the incident report rate, the recordable incident rate, and the lost workday cases rate with restricted days. All four composite discomfort scores were negatively correlated with the incident report rate. Cumulative difference ($r = -.41$), range score ($r = -.43$), and the grand mean ($r = -.55$) showed a moderate correlation. The range score ($r = .51$) showed the strongest correlation with the recordable incident rate. Likewise, the range score ($r = .70$) showed the highest correlation with the lost workday case rate.

Injury severity was measured by the number of lost workdays, and the net claim loss rate. Again, the range score showed the highest correlation with the lost workdays rate ($r = .84$) and claim loss rate ($r = .85$). The difference score was moderately correlated with lost workdays rate ($r = .42$) and claim loss rate ($r = .55$). The grand mean and maximum scores were poorly correlated with both lost workdays rate and claim loss rate.

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3.4. Task Analysis

The videotape of each job classification was reviewed to identify and document job tasks. The work sampling design enabled the proportion of the working day devoted to each task to be estimated. Work activity and non-work activity percentages were calculated for each job based on an 8-hr workday. The percentage of working time was as follows: press operator, 83; carton stripper, 51; glue line operator, 78; and glue line QPA, 76.

3.5. Postural Stress

The postural stress analysis was performed by reviewing the videotapes of work activity for each job classification. A specific frame was selected for analysis and a freeze frame feature was used to maintain the image on the monitor. The coded posture data were entered into an electronic database and tabulated according to posture categories. Output results were presented as the percentage of time spent in each posture category. Postural results are shown in Table 1.

3.6. Biomechanical Stress

Compressive force was estimated for each observation from biomechanical analysis. The force exerted and joint angles recorded on the coding sheets were entered into the biomechanical model (University of Miami, 1986), and the compressive force estimates calculated for each observation were then entered into an electronic spreadsheet and totaled to compute the cumulative biomechanical stress. The cumulative biomechanical stresses for each job classification calculated for one shift were as follows: press operator, 177 kN; carton stripping operator, 200 kN; glue line operator, 133 kN; and glue line QPA, 146 kN.

An illustration of the variation in estimated compressive forces experienced by the workers during the workday is shown in Figure 1. Such forces can be related to the spinal compression tolerance limits. The damage load values calculated for each job were as follows: press operator, 4530 N; carton stripping, 5903 N; glue line operator, 4079 N; and glue line QPA, 4823 N.

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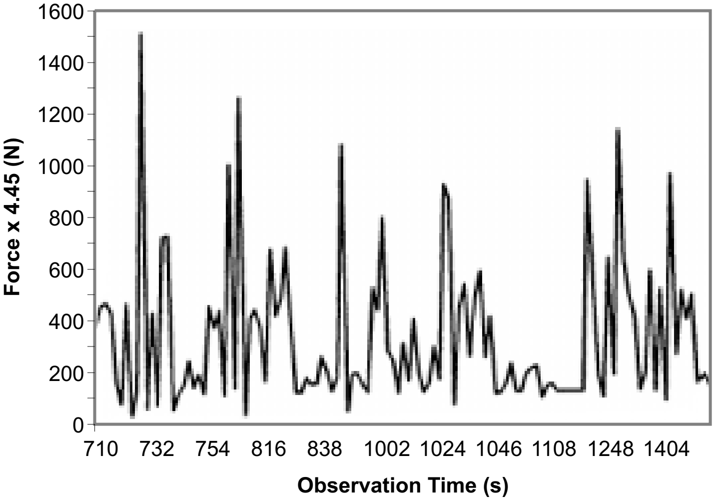

Figure 1. Example: recording of biomechanical stress (N) over time for the carton stripper.

3.7. Relationships Between Physical Stress and Strain

Table 2 shows the comparisons made at the job classification level of analysis. The incidence rate for recordable injuries, I(RI), was used as the measure of injury frequency. Injury severity was measured by the number of lost days rate with restricted days, DAYS. Postural stress was measured in terms of the percentage of the workday spent in non-neutral postures, %NNP. Cumulative biomechanical stress or loading, CBL (kN), was used as the measure of biomechanical stress.

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Figures 2 and 3 illustrate the relationships between postural stress and observed musculoskeletal injury frequency. A correlation matrix (see Table 4) was developed from the summary results to explore the strength of the relationship between the injury frequency and severity, perceived discomfort level, and postural stress. Because the biomechanical analysis estimated low back compressive forces, Table 5 was developed for the back. Injury frequency was measured using the incident report rate, I(N). The relationship between postural stress for the back and the rate of incident reports of

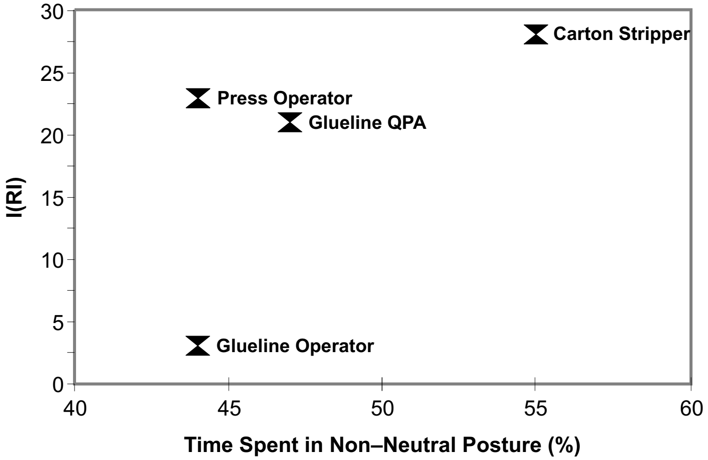

Figure 2. Postural stress versus frequency of the observed musculoskeletal injury. *Notes*. I(RI)—recordable incident rate, QPA—quality production associate.

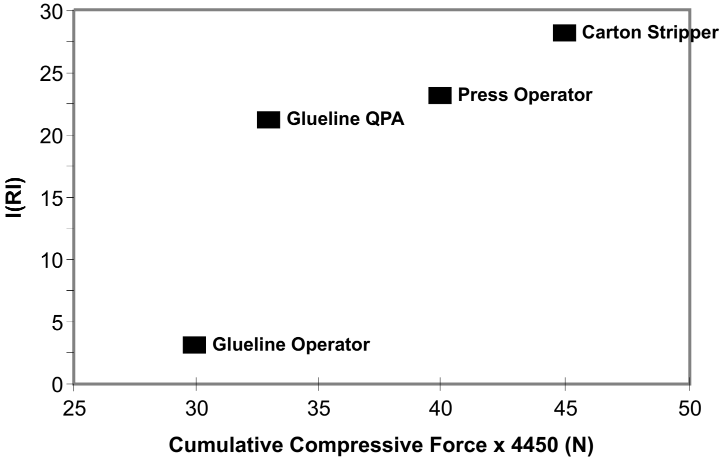

Figure 3. Cumulative compressive force versus frequency of the observed musculoskeletal injury. *Notes*. I(RI)—recordable incident rate, QPA—quality production associate.

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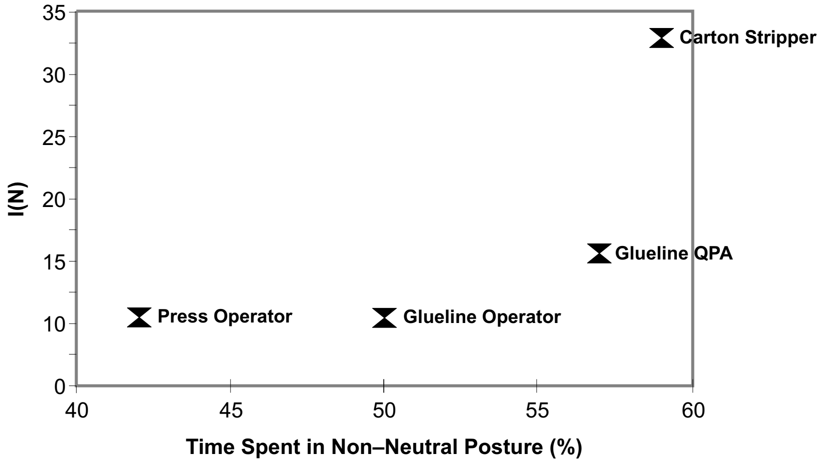

Figure 4. Postural stress of the back versus back incidents. *Notes*. I(N)—incident eport rate, QPA—quality production associate.

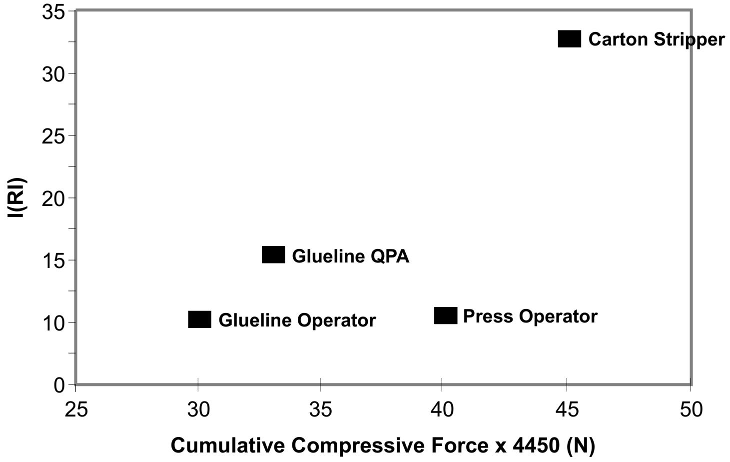

Figure 5. Cumulative compressive force versus back incidents. *Notes*. I(RI)—recordable incident rate, QPA—quality production associate.

back injury are shown in Figure 4. Biomechanical stress and the rate of incident reports for back injury are illustrated in Figure 5. In general, it was observed that the injury rate and rate of incident reports increased with (a) an increase in the percentage of time spent in non-neutral postures and (b) an increase in cumulative biomechanical loading.

TABLE 4. Stress/Strain Correlations for All Body Regions

	All Body Regions			
	I(RI)	T(3)	%NNP	CBL
I(RI)				
T(3)	–.779			
%NNP	.638	–.014		
CBL	.847	–.508	.719	
DAYS	.642	–.589	.315	.154

Notes. I(RI)—recordable incident rate, T(3)—end of day grand mean, %NNP—percentage of time in non-neutral postures, CBL—cumulative biomechanical loading, DAYS—number of lost workdays rate.

TABLE 5. Stress/Strain Correlations for Back

	Back		
	I(N)	T(3)	%NNP
I(N)			
T(3)	.034		
%NNP	.737	.622	
CBL	.740	–.644	.128

Notes. I(RI)—recordable incident rate, I(N)—incident report rate, T(3)—end of day grand mean, %NNP—percentage of time in non-neutral postures, CBL—cumulative biomechanical loading.

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4. DISCUSSION

The musculoskeletal history survey clearly demonstrated the prevalence of musculoskeletal problems experienced by employees at the facility. Prevalence rates in excess of 50% were reported for the low back (65%), the wrist (60%), and the ankle (53%). In addition, with the exception of the toes (18%), at least one third of the respondents reported “trouble” in the other body areas: shoulder (48%), elbow (35%), fingers (36%), neck (42%), upper back (43%), hip (33%), and knee (35%). These results are believed to adequately represent the point prevalence of musculoskeletal disorders for the respondents, because this survey was derived from the Nordic questionnaires, which have been used extensively, and shown to be reliable (Kuorinka et al., 1987). It must be noted, however, that the respondents were participants who voluntarily completed and returned the survey booklets. Dickinson et al. (1992) have found that participants who voluntarily respond were more

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likely to have musculoskeletal problems. Hence, actual prevalence rates may be lower than the results reported.

In this study, it was expected that the discomfort scores would be distributed across the wide range of values. However, the reported scores were concentrated in the range form 0 to 3. These results from musculoskeletal discomfort survey have important implications. First, a distribution of scores over the entire range should not necessarily be expected to occur. Although this finding may seem trivial, a careful re-reading of the Corlett and Bishop (1976) article shows that low scores are consistent with work performed at less than 60% of the endurance limit. Second, low scores may emphasize the insidious nature of musculoskeletal disorders, in that they are simply not perceived by workers. Hence, chronic problems arise because dose rates are low enough, so that workers tolerate prolonged exposure. This is an important implication, because it presents a substantial and fundamental problem with respect to the use of subjective data collection techniques for the purpose of assessing the risk of musculoskeletal disorders. In this study, workers rated perceived body discomfort low, exhibiting relatively low sensitivity to the risk of musculoskeletal injury. In short, more research is needed to understand the relationship between perceived discomfort and the risk of musculoskeletal injuries, as well as the most appropriate technique for soliciting meaningful input from workers. Likewise, additional research is needed to examine which aggregate measures of perceived discomfort are best associated with the risk of injury. In this research, percentage of discomfort scores greater than 5 ($r = .51$) was associated more strongly with the injury rate than either the mean score after 8 hrs ($r = -.26$) or the cumulative difference score ($r = .24$). Moreover, the percentage of scores greater than 5 was highly correlated with injury severity in terms of lost workdays ($r = .84$) and claim costs ($r = .85$).

Stress analysis focused on two risk factors associated with musculoskeletal injuries, specifically posture and force. Although these factors addressed the primary activity of each job, there were notable limitations. Because the results were based on a videotape sample, the adequacy of the results depends upon the degree to which typical job activities were represented. Likewise, only a small cross-section of workers, all on one shift, were videotaped. Finally, the effects of repetition were not analyzed. With these limitations recognized, some preliminary conclusions may be drawn.

Postural stress ($r = .63$) and biomechanical stress ($r = .85$) were both highly correlated with injury rates. This suggests that either technique is useful for the analysis of work activity for the purpose of preventing

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musculoskeletal injuries. If our results are confirmed in a more comprehensive study, then the postural analysis is likely to be preferred by industry. Postural analysis utilizes directly observable data, whereas biomechanical models use a number of simplifying assumptions. Moreover, the postural analysis system developed for this study requires fewer data input variables than those required for most biomechanical models. The number of input data items directly impacts analysis time, and therefore cost.

Suitable tolerance limits for exposure to postural and biomechanical stresses in the workplace remain elusive. An examination of the results of this study suggests some preliminary levels for postural stress tolerance. In terms of the incidence of back injury reports, the two job classifications with the higher incidence rates involved working in non-neutral posture in excess of 50% of the workday. In terms of the incidence rate for recordable injuries, the higher incidence rates were found for the job classifications with non-neutral posture exceeding 45% of the working day. Whereas an increased rate of low back injury has been previously associated with 10% of the workday spent in non-neutral posture (Keyserling, Punnett, & Fine, 1988; Keyserling, Stetson, Silverstein, & Brouver, 1993), this research indicates a dramatic increase in injury rate may occur when non-neutral posture exceeds 45 to 50% of the workday. Hence, the injury rate itself may change at a different rate, depending on the amount of time spent in non-neutral postures.

The rate of injury may be low for jobs that require non-neutral postures less than 10% of the day, increase moderately between 10 and 45%, and then increase sharply for jobs performed in non-neutral posture more than 45% of the workday. For cumulative biomechanical stress, the overall incidence rate of recordable injuries, increased with increasing cumulative biomechanical stress. However, when the damage load concept was applied, the estimated compressive forces for the majority of observations were found to be far below the calculated damage load. Moreover, the damage load appeared more applicable as an upper limit or injury threshold level based on the results calculated for carton stripping.

Aside from its role in determining the number and schedule of observations used for physical stress analysis, work sampling serves an important role in the ergonomic assessment of work activity. The technique provides both a description and a duration of work tasks. The use of work sampling revealed that the carton stripper was only actively engaged in stripping tasks 50% of the workday. This result has a critical implication relative to risk exposure. Payroll data, specifically work hours, have been used and reported throughout the literature a basis for determining a worker's risk exposure. Likewise, payroll hours are used as the basis for performance data typically reported to government agencies or insurance underwriters. However, this practice is likely to be misleading. Certainly, an accurate measure of exposure is needed to direct efforts and allocate resources in an effective manner. Accurate exposure hours would also provide a better evaluation of administrative controls such as job rotation.

The results of this research confirm that the degree to which postural and cumulative biomechanical stress analyses can be useful techniques for reducing the risk of injury in industry. In particular, the research provided insight into the relationship between estimated compressive force and both actual injury experience and perceived physical strain. Likewise, this research investigated the relationship between assessment and actual injury experience. Continued efforts are needed to examine the relationship between injury experience and assessment techniques.

Conclusions from this research may be summarized as follows:

- The use of payroll hours in the calculation of incidence rates is likely to understate the actual rates of musculoskeletal injury;
- Subjective ratings of postural discomfort concentrated at the low end of the measurement scale;
- Low postural discomfort scores indicate that workers exhibited low sensitivity to such a measure of risk of musculoskeletal injuries;
- Postural and cumulative biomechanical stress analyses were strongly associated with the musculoskeletal injury rate;
- Musculoskeletal injury rate increased sharply when exposure to the non-neutral postures exceeded 45% of the workday;
- The damage load appeared more applicable as an upper limit or injury threshold level;
- Work sampling can play an important role in ergonomic assessment of work activity by identifying the nature and sequence of work tasks and measuring the amount of time devoted to work activity and specific tasks.

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