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Prediction of Overexertion Injuries Using Biomechanical and Psychophysical Models*

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This paper summarizes a three year epidemiological study conducted in five large industrial plants in order to evaluate the validity of two alternative modeling approaches to overexertion injury prediction. Detailed biomechanical and psychophysical job evaluations were performed for 55 industrial jobs comprised of 2934 potentially stressful manual materials handling tasks. The medical experiences of 6912 incumbent workers were monitored retrospectively for two years and prospectively for one year to establish a data base for comparison of the different models. The results show that each of the models can be used to predict both the incidence and severity of certain overexertion types of injuries such as contact, musculoskeletal and back injuries. The application of these models to identify or design administrative and engineering controls, however, may be limited as a result of the inherent correlation between the available indices and multifaceted jobs.

Introduction

The adverse effects on the human body caused by manual materials handling have been recognized for a long time. A number of recent surveys of industrial injuries show that the act of materials handling is probably the most hazardous physical activity in all general industry.⁽¹⁾ This is based upon both the injury incidence rates (numbers of reported complaints per 100 000 exposure hours) and severity rates (days lost or restricted per 100 000 exposure hours) associated with manual materials handling. Overexertion injuries in particular account for a large number (and in some industries the majority) of disabling injuries and resulting costs.⁽²⁾

In response to the need to reduce overexertion sprain and strain related injuries, two basic approaches to job evaluation — biomechanical and psychophysical — have emerged. Both of these approaches have received considerable attention in the recent literature as methods for describing and predicting which aspects of manual materials handling contribute to the risk of overexertion injury. Several existing models and derived stress indices were evaluated for their effectiveness in predicting overexertion injuries through a longitudinal industrial field study.

Detailed biomechanical and psychophysical job evaluations were performed on 55 industrial jobs identified in five major industries. The medical experiences on these jobs were documented retrospectively for two years and prospectively for one year for 6912 incumbent workers totalling over 12.6 million man-hours exposure.

Biomechanical Approach

The biomechanical approach is founded on the concept of

the human body as a structure composed of rigid links attached at the joints and moved about by the musculature. Through the use of basic mechanical principles, it is possible to calculate the resultant forces acting on any particular muscle group or joint center caused by a given physical activity. Then the resultant force requirements can be compared to population muscle strength capacities as an index of the relative stressfulness for any given task. For example, as the percentage of the population capable of exerting the necessary forces on a job diminishes, the risk of injury presumably increases.

The second concern within this approach relates to the forces acting on the lower lumbar spine. Early models, which predicted spinal stresses at the L5/S1 disc caused by lifting, showed that the resultant moment and compressive force caused by a load being lifted and body weight can be quite large.⁽³⁻⁵⁾ There are other studies which provide epidemiological support for a mechanical etiology for the incidence of low back pain.⁽⁶⁻⁸⁾

Two biomechanical indices — isometric strength and back compression — were examined in the present study based upon a previously developed, three dimensional, static model.⁽⁹⁾ This model estimates the torques and forces operating about each major joint center. The required inputs are as follows:

- 1) load in the hands;
- 2) posture (*e.g.*, standing, stooping);
- 3) task (*e.g.*, lift, lower, push, pull); and
- 4) hand location relative to the feet.

Output from the model consists of estimates of the percentage of the male and female industrial population capable of performing any given task based upon isometric strength. These estimates are determined based on the maximally stressed muscle group (at the beginning of the exertion) — in essence, a “weakest link” concept.

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For this study, a Chatillon gauge was used to measure all forces exerted. For lifting and lowering, this force was the weight of the object. For pushing (left, right, up, down and out) and pulling (in), both initial and sustained forces were recorded.

For the analyses which follow, the minimum percentage of the population capable for each study job was defined as follows:

$$ISO.MIN = \min_i (P_i) \quad \text{for } i=1, \dots, N$$

where P_i = percentage of the population capable of performing task i based upon isometric strength.

N = number of different manual exertions required in each job.

Secondly, the worst case compressive load on the L5/S1 disc was estimated for average male and female anthropometry and summarized as

$$BC.MAX = \max_i (BC_i) \quad \text{for } i=1, \dots, N$$

where BC_i = predicted compressive force on L5/S1 disk (in pounds) for task i .

The assumption of average anthropometry for computing back compression was arbitrary but necessary without a more detailed survey of incumbents. An example biomechanical analysis for one job is shown in Figure 1.

For each task the inputs are echoed, the percentage capable determined and the amount of compressive force on the L5/S1 disk computed (see Figure 1). The right hand location is measured in inches from the origin, which is set at the middle of the line connecting the ankles; left hand co-ordinates are measured relative to the right hand location. Forces are measured in pounds. For a detailed explanation of the analysis procedures and output interpretation, the reader is referred to Reference 9.

Psychophysical Approach

Unlike the biomechanical approach, the psychophysical approach focuses on the individual's perception of pain or discomfort when doing a task. This perception results from a complex integration of information the individual receives from his/her nerve endings and sensor organs in the musculo-skeletal, cardiovascular and pulmonary systems.

PLANT: B		BIOMECHANICAL ANALYSIS													
JOB NUMBER: 08															
TASK #	TASK	POSITION	# HANDS	ORIG	MAX FORCE (LBS)	RIGHT HAND LOCATION (INCHES)			LEFT HAND SEPARATION (INCHES)			PERCENT CAPABLE		BACK COMPRESSION (POUNDS)	
						V	L	H	V	L	H	MALE	FEMALE	MALE	FEMALE
100	LIFT	STAND	2	ORIG	45	47	11	20	0	-22	0	95	28	1044	905
100	LIFT	STAND	2	DEST	45	50	11	20	0	-22	0	90	11	1034	898
101	PUSH	STAND	2	ORIG	45	50	11	20	0	-22	0	97	52	268	92
101	PUSH	STAND	2	DEST	45	50	11	24	0	-22	0	97	55	305	111
102	LOWR	STAND	2	ORIG	45	50	11	24	0	-22	0	86	9	1217	1100
102	LOWR	STAND	2	DEST	45	42	11	24	0	-22	0	86	24	1254	1122
103	PULL	STAND	2	ORIG	45	42	11	24	0	-22	0	80	18	587	542
103	PULL	STAND	2	DEST	45	42	11	9	0	-22	0	99	88	489	465
104	TRQL	STAND	2	ORIG	45	42	11	9	0	-22	0	99	99	107	90
104	TRQL	STAND	2	DEST	45	27	0	10	-15	-14	-1	96	97	468	372
105	LIFT	STAND	2	ORIG	75	64	-9	6	0	-21	0	10	1	593	POST
105	LIFT	STAND	2	DEST	75	65	-9	6	-4	-21	0	4	1	588	514
106	RGHT	STAND	2	ORIG	75	65	-9	6	-4	-21	0	97	11	115	79
106	RGHT	STAND	2	DEST	75	64	11	9	0	-22	0	85	3	120	96
107	LOWR	STAND	2	ORIG	75	64	11	9	0	-22	0	70	16	764	692
107	LOWR	STAND	2	DEST	75	41	11	5	0	-22	0	99	80	581	535
108	LOWR	STAND	2	ORIG	75	41	11	5	0	-22	0	99	80	581	535
108	LOWR	SQUAT	2	DEST	75	13	11	11	0	-22	0	91	50	1057	958
109	LIFT	STOOP	2	ORIG	95	13	11	11	0	-22	0	77	29	1096	986
109	LIFT	STAND	2	DEST	95	41	11	9	0	-22	0	92	44	887	843
110	LOWR	STAND	2	ORIG	95	41	11	9	0	-22	0	92	44	887	843
110	LOWR	STAND	2	DEST	95	36	11	9	0	-22	0	92	41	898	846
120	LIFT	SQUAT	2	ORIG	50	4	8	22	0	-16	0	79	21	1220	1084
120	LIFT	STOOP	2	DEST	50	22	8	11	0	-16	0	98	90	738	651
121	LIFT	STOOP	2	ORIG	85	14	4	12	8	-8	0	79	26	1306	997
121	LIFT	STOOP	2	DEST	85	24	4	12	8	-8	0	85	37	1073	977
130	LIFT	STOOP	2	ORIG	55	18	14	19	0	-28	0	74	34	1169	1029
130	LIFT	STOOP	2	DEST	55	24	14	19	0	-28	0	80	34	1168	1002
131	LIFT	STOOP	2	ORIG	55	24	14	19	0	-28	0	80	34	1168	1002
131	LIFT	SQUAT	2	DEST	55	3	14	10	0	-28	0	98	84	643	608

Figure 1 — Example Biomechanical Job Analysis Results

PSYCHOPHYSICAL ANALYSIS

PLANT: B
JOB NUMBER: 08

TASK #	TASK	AVERAGE FORCE (LBS)	HAND LOCATION		DISTANCE TRAVELED (INCHES)	TASK FREQUENCY (TIMES/DAY)	PERCENT CAPABLE TASK		TOTAL	
			VERT (INCHES)	HORZ			MALE	FEMALE	MALE	FEMALE
100	LIFT	35	47	20	3	2.00	98	96	93	34
101	PUSH	45	50	20	4	2.00	98	97	92	75
	PUSH	35	50	20	4	2.00	91	92	54	46
102	LOWER	35	50	24	8	2.00	98	95	88	61
103	PULL	45	42	24	15	2.00	98	93	88	73
	PULL	35	42	24	15	2.00	93	86	32	60
105	LIFT	55	64	6	1	2.00	89	16	41	0
106	PULL	75	65	6	0	2.00	33	3	1	0
	PULL	55	65	6	0	2.00	38	6	0	0
107	LOWER	55	64	9	23	2.00	66	2	6	0
108	LOWER	55	41	5	28	2.00	80	16	30	0
109	LIFT	70	13	11	28	2.00	85	39	15	0
110	LOWER	70	41	9	5	2.00	81	10	28	0
120	LIFT	50	4	22	18	3.00	92	63	33	0
121	LIFT	75	14	12	10	3.00	88	50	29	0
130	LIFT	50	18	19	6	8.00	94	80	51	4
131	LIFT	50	24	19	0	8.00	94	80	51	4
132	LIFT	50	73	8	5	8.00	91	35	53	0
133	LOWER	50	78	8	44	8.00	66	4	11	0
134	LOWER	50	34	8	28	8.00	84	30	43	0
137	PULL	100	76	18	8	8.00	1	0	0	0
	PULL	90	76	18	8	8.00	0	0	0	0
138	PULL	100	74	6	0	8.00	1	0	0	0
	PULL	90	74	6	0	8.00	0	0	0	0
139	LOWER	90	74	6	39	8.00	3	0	0	0
140	LIFT	90	35	8	2	8.00	52	0	2	0
141	PULL	100	20	31	8	8.00	59	15	11	1
	PULL	90	20	31	8	8.00	16	0	0	0
142	PULL	100	21	11	0	8.00	59	15	11	1
	PULL	90	21	11	0	8.00	16	0	0	0
143	LIFT	90	21	11	14	8.00	72	8	6	0
144	PULL	77	65	22	5	8.00	26	1	0	0
	PULL	35	65	22	5	8.00	84	63	10	34
145	PUSH	77	68	22	6	8.00	87	57	46	0
	PUSH	35	68	22	6	8.00	90	91	50	38
146	PUSH	77	25	22	8	8.00	86	53	46	0
	PUSH	35	25	22	8	8.00	91	91	56	51
150	PULL	80	37	15	5	80.00	74	20	34	6

Figure 2 — Example Psychophysical Job Analysis Results

Base line data about the task stressfulness are obtained by allowing test subjects to vary one task descriptor variable, typically load, while performing a simulated work task in which the other task descriptor variables are held constant. Other task descriptor variables include the following:

- 1) type of task (lift, lower, etc.);
- 2) location of load (horizontal and vertical distance from some body reference point such as the ankles);
- 3) frequency of exertion;
- 4) distance moved (for pushes, pulls and carries); and
- 5) posture (stoop, squat, free style, etc.).

As with the biomechanical model described earlier, a Chatillon gauge was used to measure all forces. Both initial and sustained forces were recorded as well as average and maximal forces (for tasks which varied from cycle to cycle). One shortcoming of all models analyzed in this study was that the importance of dynamic body twisting/jerking and other asymmetric work was underestimated.

A series of seven studies performed at the Liberty Mutual Research Center⁽¹⁰⁾ stand out for their comprehensiveness in this regard, as does a study performed by Texas Tech University⁽¹¹⁾ (though the latter work was restricted to lifting tasks only). These studies form the basis for psychophysical

indices computed in the present study. In another study, fuzzy set modeling was applied to combine biomechanical and physiological stress indicators to investigate acceptability of a lifting task in terms of psychophysical stresses.⁽¹²⁾

The series of studies performed by the Liberty Mutual Research Center also provided the first analysis to relate psychophysical strength measurements and analyses to risk of low back injury.⁽¹⁰⁾ Based upon a follow-up questionnaire analysis of 191 cases of low back injury from 32 states,⁽¹³⁾ it was revealed that:

approximately one quarter of policy holder jobs involve manual handling tasks that are acceptable to less than 75 percent of the workers; however, one half of the low back injuries were associated with these jobs. This indicates that a worker is three times more susceptible to low back injury if performing a manual handling task that is acceptable to less than 75 percent of the working population. This also indicates that, at best, two out of every three low back injuries associated with heavy manual handling tasks can be prevented if the tasks are designed to fit at least 75 percent of the population. The third injury will occur anyway, regardless of the job. The other low back injuries not associated with heavy manual handling

TABLE I
Comparison of Job Variables Required by Three Models

Model	Type of Task	Force Required	Posture	Vertical Hand Location	Horizontal Hand Location	Travel Distance Body Movement	Frequency
Chaffin:	X	X	X	X	X		
Snook:	X	X		X	X	X	X
Ayoub:	X	X		X		X	X

tasks will also occur. Therefore, it can be concluded that the proper design of manual handling tasks can reduce up to one third of industrial back injuries.

Tables provided by Liberty Mutual contain the maximum weights which are acceptable for various percentiles of the male and female industrial population based on a normal statistical distribution.⁽¹⁰⁾ For the purposes of the present study, a computer program was developed to interpolate/extrapolate between these table values to estimate the percentage of the male and female industrial population capable of performing each specific task.

The corresponding psychophysical indices derived were

$$PSY.MIN = \min_i (P_i) \quad \text{for } i=1, \dots, N$$

and

$$PSY.AVG = \sum_{i=1}^N P_i / N$$

where P_i = percentage of the population capable of performing task i based on psychophysical strength.

The psychophysical analysis (comparable to Figure 1) is presented in Figure 2.

The last four columns of this figure present predicted percentages of males and females capable of performing each task individually at the specified task frequency all day long. These independent estimates ignore the fact that multiple tasks are performed necessarily. The last column normalizes the frequency of exertions based on the total number of exertions (summing across all tasks) per day. By considering frequency in this way (as an interexertion interval) the relative stressfulness of each exertion is overestimated. The true percentage capable of each task should lie somewhere between these two estimates.

Another psychophysical study of interest here was conducted in 1978.⁽¹¹⁾ This study was restricted to lifting tasks but provided prediction models of maximum lifting capacity as a function of worker and task variables in which male and female industrial subjects were used. Separate regression equations were generated for each of six lifting regions (floor to knuckle, floor to shoulder, floor to reach, knuckle to shoulder, knuckle to reach and shoulder to height) based on different lift frequencies (2, 4, 6 and 8 lifts/min) and object sizes (12, 18 and 24 inches in the sagittal plane). These models allow one to predict an individual's lifting capacity in

terms of the maximum acceptable weight of lift at the rate of one lift per minute for the different lifting situations.

This study also investigated several job stress indices which could be computed as weight lifted to individual (or population) capacities by task. For the purposes of the present study, two indices were used: a job severity index (JSI) and a lifting strength ratio (LSR).

The JSI was defined as the weighted average ratio of weights lifted to average population lift capacity:

$$JSI = \sum_{i=1}^N P_i (W_i / C_i)$$

where N = number of different lifting tasks in the job;

P_i = percentage of all lifting tasks of type i ;

W_i = weight lifted in task i ; and

C_i = acceptable weight for average person performing lifting task i .

Note that the definition of JSI differs from that used in the original study⁽¹¹⁾ in that instead of calculating a JSI for a population individual, this index was calculated for the average male and female study population. The fact that jobs were documented as the typical daily activity resulted in the above simplified formula for JSI.

The second index, lift strength ratio, identifies the most stressful task of the job. It can be thought of as the biomechanical-concept equivalent for psychophysical data. LSR represents the largest of the ratio of required lift weight to capacity across all tasks of a given job, *i.e.*,

$$LSR = \max_i (W_i / C_i)$$

These two indices represent, in a sense, average vs. maximal stress ratings.

TABLE II
Number of Study Jobs and Tasks by Industry

Industry	Number of Jobs	Number of Tasks	Average Number of Tasks Per Job
A	11	154	14
B	15	400	29
C	9	1045	116
D	10	75	8
E	10	1260	126

MEDICAL INFORMATION FOR EMPLOYEES ASSIGNED TO JOB:
 * = OCCUPATIONAL INCIDENTS

PERIOD ON JOB: 1-1-78 TO 2-10-80
 TOTAL HOURS: 4225

COMPLAINT DATE	BODY PART(S)	COMPLAINT TYPE(S)	DIAGNOSES	TREATMENT	DAYS REST	DAYS LOST	EXERTION	DIREC-TION	METHOD	ACTIVITY	TIME ON SHIFT
1- 6-78	HEAD		46 0 0	FIRSTAID	0	0					
1- 9-78	FOOT	*SPRN	84 0 0	FIRSTAID	0	0	YES			WALKING	2.50
1-11-78	HEAD		11 0 0	FIRSTAID	0	0					
1-18-78	HEAD		46 0 0	FIRSTAID	0	0					
3-21-78	ABDMN		52 0 0	FIRSTAID	0	0					
3-31-78	HEAD		11 0 0	FIRSTAID	0	0					
4- 3-78	FARM	*LACR	91 0 0	FIRSTAID	0	0	NO				
4- 5-78	HEAD		11 0 0	FIRSTAID	0	0					
4-17-78	NECK	*SPRN	84 0 0	FIRSTAID	0	0					
4-21-78	FINGR	*LACR	93 87 0	FIRSTAID	0	0	YES	PULL	2 HAND	WALKING	5.70
4-25-78	ABDMN		52 0 0	FIRSTAID	0	0					
4-27-78	HEAD		11 0 0	NON SPEC	0	0					
5- 2-78	HEAD	*CONT	92 0 0	FIRSTAID	0	0	YES			WALKING	0.70
5- 3-78	HAND FINGR	*FRGN	93 0 0	FIRSTAID	0	0	NO				
6- 8-78	ABDMN		4 52 0	FIRSTAID	0	0					
6-22-78	HEAD		11 0 0	FIRSTAID	0	0					
6-29-78	HEAD		11 0 0	FIRSTAID	0	0					
7-10-78	HEAD ABDMN		46 52 0	FIRSTAID	0	0					
7-25-78	HEAD		11 0 0	FIRSTAID	0	0					
7-27-78	ELBOW	*SPRN	84 0 0	FIRSTAID	0	0	YES	PULL	2 HAND	STANDING	2.00
8- 4-78	FINGR	*LACR	87 0 0	FIRSTAID	0	0	YES	LIFT	2 HAND	STANDING	7.70
8-17-78	HEAD		11 0 0	FIRSTAID	0	0					
9- 1-78	ABDMN		52 0 0	FIRSTAID	0	0					
9-11-78	FARM	*BURN	94 0 0	FIRSTAID	0	0	NO				
9-27-78	HEAD		11 0 0	FIRSTAID	0	0					
9-28-78	HEAD		11 0 0	FIRSTAID	0	0					
10-10-78	WRIST	*SPRN	84 0 0	PHYSICIAN	0	0	YES	PUSH	1 HAND	STANDING	1.50
10-19-78	HEAD		11 0 0	FIRSTAID	0	0					
10-23-78	FINGR	*CONT	91 0 0	FIRSTAID	0	0	YES	PUSH	1 HAND	SQUATING	1.50
11-20-78	OTHER		18 0 0	FIRSTAID	0	0					
12-13-78	HAND	*LACR	87 0 0	FIRSTAID	0	0	YES	PULL		STANDING	3.00
1-17-79	FINGR	CONT	91 0 0	FIRSTAID	0	0					
1-29-79	EYES	*FRGN	93 18 0	FIRSTAID	0	0	YES	PULL	2 HAND	WALKING	2.50
2- 8-79	FARM	FRAC	68 0 0	FIRSTAID	0	0					
3- 2-79	ABDMN		52 0 0	FIRSTAID	0	0					
3- 7-79	OTHER		18 0 0	FIRSTAID	0	0					
3-12-79	ABDMN		52 0 0	FIRSTAID	0	0					
3-28-79	ABDMN		52 0 0	FIRSTAID	0	0					
3-30-79	OTHER		18 0 0	FIRSTAID	0	0					
4- 6-79	ABDMN		52 0 0	FIRSTAID	0	0					
4-10-79	ABDMN		52 0 0	FIRSTAID	0	0					
5- 1-79	LBACK	*SPRN	90 0 0	PHYSICIAN	0	0	YES	LIFT	2 HAND	WALKING	5.00
5-11-79	HEAD		11 0 0	FIRSTAID	0	0					
5-17-79	HEAD ABDMN		52 11 0	FIRSTAID	0	0					

Figure 3 — Example Employee Dispensary Visit Record

Job Analysis

The analysis of each job involved observing the sequence of activities performed and recording all pertinent information relative to the above biomechanical and psychophysical models. Table I illustrates the types of information required for the three models.

Clearly, the documentation of jobs by these models involves a great deal of data collection. Table II summarizes this effort and illustrates that some plants had relatively simple jobs, such as Industry D, in that few tasks were required to describe the activities, whereas others had jobs containing many individual tasks, such as Industry E. Given that the description of each task within a job requires 21 pieces of information, approximately 62 000 pieces of data were collected during the job analysis process.

Medical Surveillance

Incumbent employee work histories (in terms of job expo-

sure hours) and medical experiences (in terms of dispensary visits) were monitored retrospectively for two years and prospectively for one year to provide the measures for evaluating the proposed models. Work history information in terms of starting and ending dates for each employee/job assignment permitted individualized incidence and severity rates. Only jobs with ten or more hourly employees were included in the study.

Medical dispensary visit documentation included date of incident, body part affected, complaint type, diagnosis (coded by ICD-), care given, days restricted and days lost (if any) per employee. A partial listing of the medical visit record for employees assigned to a selected job is illustrated in Figure 3.

As expected, the medical surveillance information collection process also generated a voluminous data set. A computer data management system was developed to organize and report the resultant 375 000 pieces of personnel information.

TABLE III
Data Base Sample Sizes by Industry

Industry	Study Participants	Number of Job Assignments	Dispensary Visits
A	4186	35 862	7140
B	905	1205	8256
C	434	560	277
D	1024	1311	4380
E	363	584	2852
Total	6912	39 522	22 905

TABLE IV
Data Collection by Database

Database	Variables	Number of Observations	Total Number of Data Collected
Employee	5	6912	34 560
Assignment	4	39 522	158 088
Dispensary visit	8 (minimum)	22 905	183 240
Total			375 888

TABLE V
Correlation Between Job Stress Indices

ISO.MIN	1.00					
PSY.MIN	0.66	1.00				
PSY.AVG	0.38	0.40	1.00			
BC.MAX	-0.73	-0.70	-0.44	1.00		
JSI	-0.49	-0.41	-0.48	0.59	1.00	
LSR	-0.65	-0.66	-0.42	0.78	0.74	1.00
ISO.MIN	PSY.MIN	PSY.AVG	BC.MAX	JSI	LSR	

TABLE VI
Comparison of Average Stress Indices Between Plants

Plant	ISO.MIN	PSY.MIN	PSY.AVG	BC.MAX	JSI	LSR
A	40.6	39.6	93.0	1210	0.39	1.05
B	19.7	29.5	81.3	1420	0.85	1.58
C	67.2	38.4	92.8	1127	0.69	1.15
D	80.4	79.5	91.9	825	0.57	0.65
E	47.7	59.5	95.3	1043	0.53	0.92

Tables III and IV show the number of employees, job assignments and medical incidents encountered in each industry. There were more job assignments than employees, in general, as a result of intrastudy job transfers. Industry A rotated employees between jobs with greater frequency than the other industries (as shown in Table III). The jobs within Industries C and E involved many more tasks (per job) than the other industries as shown in Table II. These inherent differences between industries — in addition to fundamentally different products and processes as well as injury reporting protocols — were a primary basis for the stratified analyses which follow. Another point to note is that all dispensary visits were recorded but only overexertion related injuries are reported herein.

Three basic categories of incident-types have been used in summarizing overexertion incidents for the purposes of this study, namely:

- 1) contact incidents;
- 2) musculoskeletal incidents excluding back problems; and
- 3) back incidents.

Contact incidents included injuries — such as lacerations, abrasions, blisters, contusions, thermal and chemical burns — and contact with airborne foreign bodies (typically involving the eyes). Musculoskeletal incidents included sprains and strains of muscles and/or connecting tissues (not including the low back), fractures and joint diseases. Back incidents were coded independently to include sprains and strains of the back, degenerative disc disease, as well as ill-defined pain.

Incidents within one or more of the above categories were called overexertion related. It is important to note that the term incidents in this context does not imply injury or medical pathology.

Job Analysis Results

Table V illustrates the correlations between the job stress indices. While there is a significant correlation between the alternate indices, it is also clear that the relatively low magnitudes suggest that they cannot be substituted. The level of significance, α , for all of these coefficients was less than or equal to 0.05. Table VI further illustrates the inherent differences between the study plants in terms of the average job stress indices.

Medical Analysis Results

Both “lost time” and “non-lost time” medical dispensary visits were examined for their relation to the job stress indices. Similar patterns were found for both types of incidents (regardless of severity) so the combined data are presented here. Figure 4 shows the incidence rates for contact, musculoskeletal and back incidents in relation to the isometric strength requirements in terms of ISO.MIN. An analysis of variance confirmed the apparently significant ($p > 0.95$) negative correlations between the incidence rates and the minimum percentage capable for *all* types of incidents.

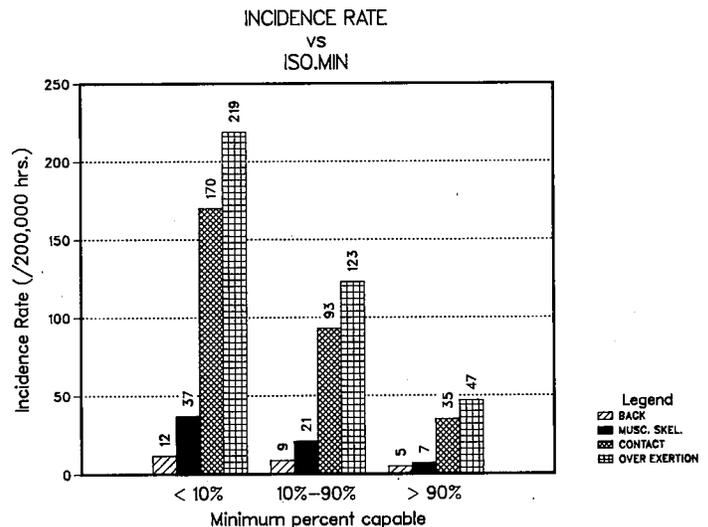


Figure 4 — Overexertion Incidence Rates vs. ISO.MIN

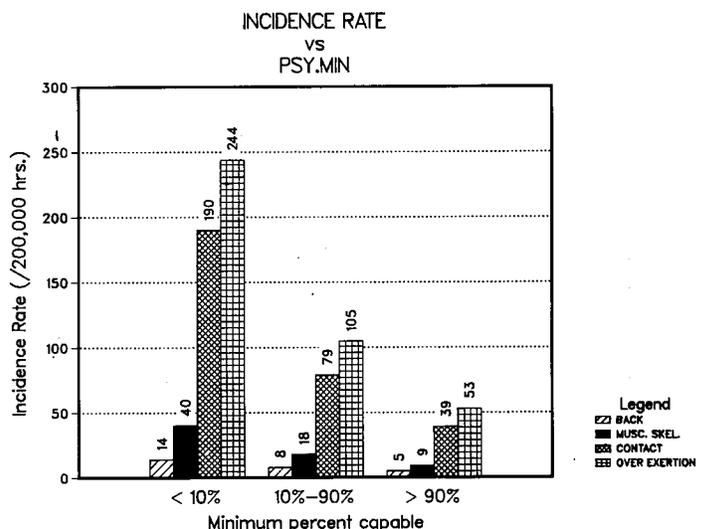


Figure 5 — Overexertion Incidence Rates vs. PSY.MIN

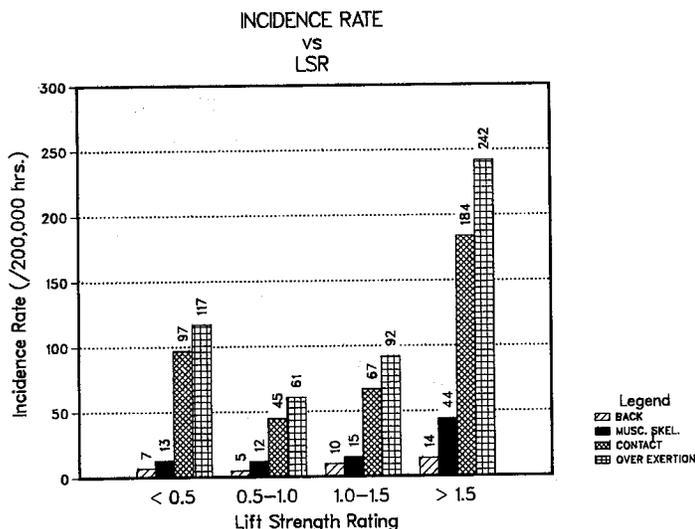


Figure 6 — Overexertion Incidence Rates vs. LSR

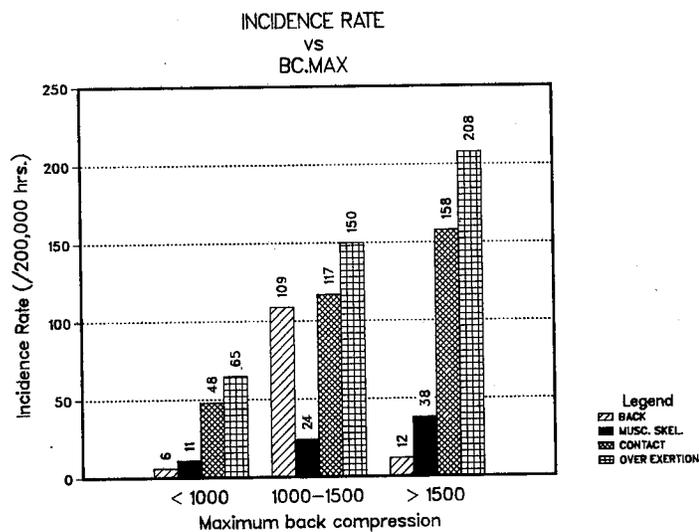


Figure 7 — Overexertion Incidence Rates vs. BC.MAX

To insure that these observed effects were not simply differences between industries, an analysis of covariance was performed. The obvious differences between the participating industries (in terms of the stressfulness of selected jobs, availability and breadth of dispensary services, inequalities in job exposures, etc.) were highly significant ($p > 0.99$) in all cases. On the other hand, the intercorrelations between industries were not strong enough to mask the effects of job stressors.

The analysis was adjusted further for inequalities in worker exposures (between jobs and physical stress indices) through a stratified analysis. Each job was first classified according to each job severity index. Next, the medical incidence and severity rates were recomputed by pooling all medical incidents and exposure hours across jobs within the same severity classification. While the absolute magnitudes of the observed effects of physical job stressors were ameliorated somewhat in these analyses, the statistical significance of results was enhanced.

Comparable results in which the psychophysical approach was used are shown in Figure 5. Here again, a strong nega-

tive correlation between each incident type and the predicted minimum percentage capable (PSY.MIN) was observed. This was also the case for adjusted analyses as mentioned above.

The pooling of tasks implied by the index, PSY.AVG, was particularly ineffective in predicting overexertion incidents. The averaging of high frequency, nominally stressful tasks, together with occasional highly stressful tasks tended simply to obscure the differences between jobs. Since the study did not specifically stratify jobs based on exertion frequencies by design, it was not possible to separate out an "acute" vs. "cumulative trauma" etiology.

Incidence rates vs. the lift strength ratio (LSR) and maximum back compression (BC.MAX) are shown in Figures 6 and 7. Significant positive correlations were observed for all types of injuries with respect to back compression estimates. In the case of the LSR, the same was true for back complaints and other musculoskeletal incidents. Contact incidents, on the other hand, exhibited a "U" shaped relationship with LSR with a low LSR also associated with a significantly elevated incidence rate. While it was observed that jobs with low LSR ratios were also somewhat more repetitive in content (presumably leading to increased exposure to submaximal stress) than jobs with very high LSRs, this did not appreciably explain the observed reversal.

An additional analysis adjusted the LSR index for each job by gender (based on the composition of incumbents on each study job). In this way, jobs which were occupied predominantly by a female workforce were rated as more

TABLE VII
Correlation Between Job
Stress Indices and Injury
Incidence Rates^A

ISO.MIN	-0.13	-0.21	-0.04	-0.15
BC.MAX	0.14	0.21	0.13	0.17
JSI.MALE	-0.14	-0.12	-0.21	-0.15
JSI.FEM	-0.13	-0.10	-0.20	-0.14
PSY.MIN	-0.20	-0.29	-0.16	-0.24
PSY.AVG	0.13	0.07	0.22	0.14
	ILC	ILM	ILB	ILO

^A $r = 0.35$ significant at $\alpha = 0.01$; $r = 0.54$ significant at $\alpha = 0.05$.

TABLE VIII
Correlation Between Job
Stress Indices and Injury
Severity Rates^A

ISO.MIN	-0.06	-0.19	0.17	-0.02
BC.MAX	0.16	0.24	0.03	0.19
JSI.MALE	-0.19	-0.18	-0.19	-0.26
JSI.FEM	-0.19	-0.16	-0.20	-0.25
PSY.MIN	-0.15	-0.22	-0.09	-0.21
PSY.AVG	0.15	0.06	0.17	0.17
	STC	STM	STB	STO

^A $r = 0.35$ significant at $\alpha = 0.01$; $r = 0.54$ significant at $\alpha = 0.05$.

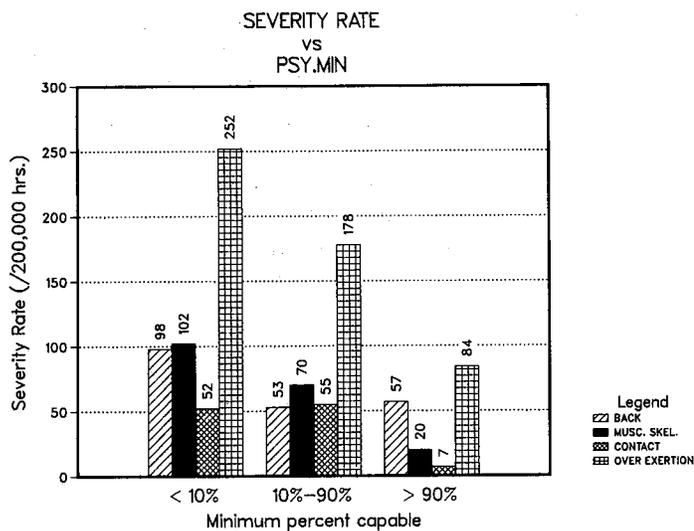


Figure 8 — Overexertion Severity Rates vs. PSY.MIN

stressful (relative to incumbent females) than an equivalent job populated predominantly by males. The nominal improvements in prediction were not statistically significant ($p < 0.90$).

The job severity index (JSI) was related only to severity of the overexertion incidence rates ($\alpha \leq 0.06$). Presumably, the weighting of ratios implied by this index suffers from the same deficiency as PSY.AVG mentioned above. Tables VII and VIII show the correlation between stress indices and injury/severity rates. It should be noted from these tables that none of the indices explain more than 10% of the variance in the rates ($R^2 < 0.10$).

In terms of the ability of these models to predict overexertion incident severity, the results were less consistent. As illustrated in Figures 8 through 10, there were significant correlations between each of PSY.MIN, LSR, and BC.MAX and severity rates (in days lost or restricted per 200 000 exposure hours). It was observed that the psychophysical minimum percentage capable was a good predictor of back incident and other musculoskeletal incidents severity. The severity of contact incidents also was related to PSY.MIN and elevated for all but the most trivial job ($PSY.MIN > 90\%$).

The LSR index and the BC.MAX index also were observed to be related statistically to each of the overexertion injury-types, though the effects were monotonic only for the combined overexertion injury rates. It is not clear whether these inconsistencies were due to possible physician biases (influence of job requirements on the decision to return to work after injury) or a lack of specificity of lost time to injury risk.

Conclusions

Based on the results of this study, it is concluded that overexertion injuries can be related to physical job stress. In particular, describing extreme job requirements — such as the most stressful tasks — seems to be more predictive, in general, than those indices which represent aggregations. The averaging or pooling of stressful and nonstressful

aspects tends to obscure the differences between jobs which contribute most to overexertion injury.

The percentage of the population capable of performing the most stressful aspect of a job (based on either psychophysical strength, PSY.MIN, or upon isometric strength, ISO.MIN) is perhaps the best simple index of this type. The biomechanical criterion of maximal back compression (BC.MAX) appears to be a good predictor not only of risk of back incidents but of overexertion injuries in general. This may be due in part to the fact that jobs which place a lot of stress on the L5/S1 disc also tend to stress other parts of the musculoskeletal system. This artifact of normal, manual materials handling jobs is not a necessary requisite.

The inherent correlation between different aspects of musculoskeletal stress is difficult if not impossible to separate. In terms of describing populations of jobs and composite risk of overexertion, however, these correlations can be used advantageously in identifying problem jobs. The challenge then becomes one of developing more refined models to prescribe the appropriate administrative or engineering controls necessary to reduce the hazard.

Glossary

ILC	Incidence rate for contact injuries that have resulted in lost days (per 200 000 hr of exposure).
ILM	Incidence rate for musculoskeletal injuries that have resulted in lost days (per 200 000 hr of exposure).
ILB	Incidence rate for back injuries that have resulted in lost days (per 200 000 hr of exposure).
ILO	Incidence rate for overexertion related injuries that have resulted in lost days (per 200 000 hr of exposure).
STC	Severity rate for all contact injuries (per 200 000 hr of exposure).
STM	Severity rate for all musculoskeletal injuries (per 200 000 hr of exposure).

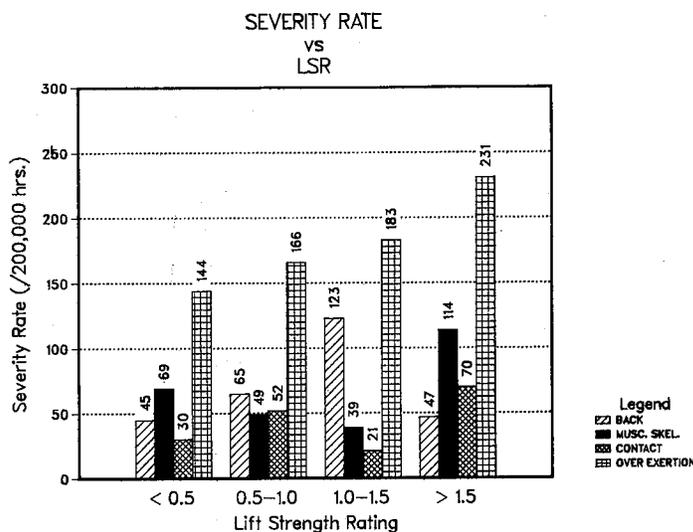


Figure 9 — Overexertion Severity Rates vs. LSR

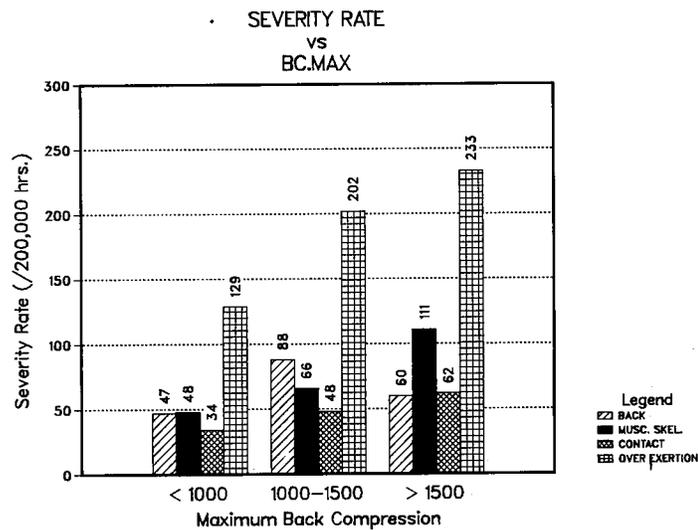


Figure 10 — Overexertion Severity Rates vs. BC.MAX

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STB	Severity rate for all back injuries (per 200 000 hr of exposure).
ISO.MIN	Minimum percentage of the population capable for each study job (based on biomechanical analysis).
BC.MAX	Maximum predicted compressive force on L5/S1 disk for each study job (based on biomechanical analysis).
JSI.MALE	Job severity index for male workers in the study.
JSI.FEM	Job severity index for female workers in the study.
PSY.MIN	Minimum percentage of the population capable of performing each study job (based on psychophysical analysis).
PSY.AVG	Average of the percentage of the population capable of performing tasks of each study job (based on psychophysical strength).