Calculating the economic benefits of interventions to prevent work-related low back pain: a systematic review of biomechanical measures and cost-related health outcomes

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Abstract

The objective of this investigation was to use published literature to calculate predicted reductions in workplace back injuries, along with their associated costs, related to specific changes in biomechanical exposure levels. A systematic literature review was conducted to identify workplace epidemiologic studies which could be used to quantify relationships between several well-recognized biomechanical measures of back stress and economically relevant outcome measures. Thirteen research studies which fulfilled search criteria were found. Sample calculations of cost reductions were carried out using a mathematical model that incorporates both biomechanical and financial modeling techniques. Results were intended to provide safety practitioners with information that could be applied to their own workplace situations to estimate costs and benefits of ergonomic intervention strategies before they are implemented.

Keywords: back pain, epidemiology, biomechanics, ergonomics, intervention, cost-benefit analysis

1. Introduction

Low back pain is the most common reason for days away from work, according to U.S. Bureau of Labor Statistics data (Courtney and Webster, 1999). In 1994, for example, there were 490,094 low back sprains/strains/tears that resulted in at least one day away from work, with an incidence rate of 60.7 per 10,000 full-time workers. Data from Washington State's Department of Labor and Industries, a workers' compensation state fund insurer, demonstrated that non-traumatic soft-tissue musculoskeletal disorders of the back comprised 14.4% of all claims between 1992 and 2000, accounting for $1.5 billion in direct costs (Silverstein and Kalat, 2002). Authors have estimated that 37% of low back pain world-wide is attributable to occupation (Punnett *et al*. 2005). Clearly, these disorders represent a significant public health problem and economic burden to employers.

While work-related musculoskeletal disorders might be controlled by any number of means, in the absence of national ergonomics legislation, an alternative approach is to demonstrate the economic benefits that can come from investing in ergonomic interventions. In the U.S., the National Occupational Research Agenda, developed by the National Institute for Occupational Safety and Health (NIOSH), has identified economic analysis of ergonomic interventions as a priority. Increasingly, health and safety practitioners are interested in implementing interventions, but are forced to demonstrate potential economic benefits before they are allowed to allocate resources to a project. Although case studies of profitable investments in ergonomics interventions do exist, they often have methodological limitations and are difficult for safety professionals to use in a direct manner. Many interventions do not examine health effects as outcomes, instead choosing to document only changes in environment, exposure, or process (van der Molen *et al.* 2005). Those epidemiology studies that do utilize health-related outcomes may use measures that vary in severity from pain symptom reports to disability and lost time (Cole *et al*. 2003). Many intervention effectiveness analyses have done little or no objective measurement of exposures related to injury reduction, for example, the many studies that have examined back belt effectiveness (van Poppel *et al*. 1997).

The objective of this investigation was to calculate predicted reductions in back injuries, along with their associated costs, related to specific changes in biomechanical exposure levels. A systematic literature review was conducted to identify workplace epidemiologic studies which could be used to quantify relationships between several well-recognized biomechanical measures of back stress (related to lifting, spinal compression, and awkward postures) and economically relevant outcome measures (such as workers' compensation claims, sickness/accident claims, and Occupational Health and Safety Administration (OSHA) log injury reports). Results were intended to provide safety practitioners with information that could be applied to their own workplace situations to estimate costs and benefits of intervention strategies before they are implemented. Sample calculations of cost reductions are carried out using a mathematical model that incorporates both biomechanical and financial modeling techniques.

2. Methods

2.1. Literature search

A systematic literature review was undertaken to identify publications that examined relationships between biomechanical risk factors and relevant back disorder outcomes. Criteria

Table 1. Epidemiologic studies of back disorder using biomechanical measures of exposure and outcome definitions related to costs

Author	Population/ Study design	Biomechanical exposure method	Outcome definition/ measure
Chaffin and Park (1973)	Electronics mfg/ prospective	Lifting strength rating	Visits to Med. Dept because of back complaints/ rates per 1 000 man-weeks
Liles *et al.* (1984)	28 companies with manual lifting/ prospective	Job severity index	Lifting injuries to back from workers' compensation, company records/rates per 100 full-time equivalents
Herrin *et al.* (1986)	5 large industrial plants with manual materials handling/ prospective	3-dimensional static model (Garg and Chaffin, 1975), Lifting Strength Ratio	Dispensary visits for back incidents, total and lost-time/ rates per 200 000 person-hrs
Ljungberg *et al.* (1989)	Nursing assistants, Warehouse workers/ cross-sectional	Shoes with strain gauges, Ovako Working posture Analysis System (Karhu, 1977)	Back strain injury reports from Swedish Information System on Occupational Injuries/ rates per 1 000 employed
Punnett *et al.* (1991)	Auto workers/ case-control	3-dimensional biomech-anical strength model (Chaffin and Andersson, 1991), video recordings	Back pain reported to medical dept/Odds Ratios

Table 1, continued. Epidemiologic studies of back disorder using biomechanical measures of exposure and outcome definitions related to costs

Author	Population/ Study design	Biomechanical exposure method	Outcome definition/ measure
Garg and Owen (1992)	Nursing assistants in nursing homes/ prospective (intervention)	3-dimensional static biomechanical model (Garg and Chaffin, 1975)	Accident investigations, OSHA reports for back injuries/rate per 200 000 person-hrs
Marras *et al.* (1993) Marras *et al.* (1995) Marras *et al.* (1999)	48 manufacturing companies, 403 jobs/ cross-sectional	Lumbar Motion Monitor, Revised NIOSH lifting equation (Waters *et al.* 1993)	Back injuries from medical records and OSHA reports/ injury rate categories (per 200 000 person-hrs)
Wickstrom *et al.* (1993)	Sheet metal company/ prospective (intervention)	Video analysis, 2-dimensional static strength prediction program (University of Michigan, 1986)	Days sickness/absence due to low back disorder
Kerr *et al.* (2001)	Auto workers/ case-control	2-dimensional quasi-dynamic biomechanical model (Neumann, 1999); direct observation	Report of low back pain episode to occupational nursing station/ Odds Ratios
Hoogendoorn,*et al.* (2002)	21 companies/ prospective	Video recordings, direct force recordings	Sickness/absence due to low back pain >3 days/Relative Risks
Stuebbe *et al.* (2002)	Paperboard packaging plant workers/ prospective	Video recording analyses, biomechanical analysis system (University of Miami, 1986)	Back disorders from workers compensation & OSHA reports/ rates per employee work-hrs (not described)

Table 1, continued. Epidemiologic studies of back disorder using biomechanical measures of exposure and outcome definitions related to costs

Author	Population/ Study design	Biomechanical exposure method	Outcome definition/ measure
Sesek *et al.* (2003)	Auto plants/ prospective	Revised NIOSH lifting equation (Waters *et al.* (1993)	Low-back-related first-time medical visits/Odds Ratios
Luijsterburg *et al.* (2005)	Bricklayers/ prospective/(intervention)	Video recording analysis, Task Recording and Analysis on Computer System (Frings-Dreisen, 1995)	Ave. duration sickness/absence due to back problems/(no. days)

for exposure measures were that direct observation or videotaping of study participants (or a sample thereof) must have been carried out, and that standard biomechanical methods, indices, or models must have been used to quantify postures, spinal compression, or lifting weight/frequency/duration (vibration as a risk factor was not considered). The study must have expressed back outcomes as workers' compensation claims, sickness/accident claims, OSHA log or other company-specific incident reports. Additional criteria included that the paper must have studied an occupational group in its usual work environment (experiments were excluded) and the study must have been conducted in an industrial, health care, construction or other work environment with potential for heavy exposure to physical back stressors. Office environment studies were excluded.

A search of Medline and NIOSHtic-2 databases were conducted for years 1966 through September of 2006, using broad search criteria: for Medline, using the keyword "back", including all related subject headings and subheadings; for NIOSHtic-2, additional search criteria were imposed, adding keywords "epidemiology" or "biomechanics" to the above strategy. Eighty-eight professional journals were targeted, in the following categories: general medicine, epidemiology, biostatistics, public health, occupational/environmental health and medicine, industrial hygiene, biomechanics, ergonomics, orthopedic medicine, nursing, physical medicine and rehabilitation, rheumatology, and injury prevention. The journals "International Journal of Industrial Ergonomics", "Clinical Biomechanics", and "Occupational Ergonomics" are not indexed by Medline and were searched via their individual websites. For the journal "Spine", search criteria were identical to those used for NIOSHtic-2. A complete list of targeted journals is available upon request. Abstracts were examined to identify potential papers of interest; additional papers were identified by examining references.

2.2 . Workers' compensation data

Information on rates, costs, and time-loss days for workers' compensation claims related to back injuries was obtained from published data from Washington State, years 1992-2000 (Silverstein and Kalat, 2002). In Washington, employers are required to obtain workers' compensation insurance through the state's industrial insurance system unless they are able to self-insure; the State Fund data cover two-thirds of workers in this state.

3. Results

A total of 7,470 publications were identified in the literature search. Fifteen articles, describing 13 research studies, were found which fulfilled search criteria.

Outcome definitions were fairly homogeneous, including workers' compensation claims, OSHA log reporting, sickness/absence reports, lost work-days, and various company-specific mechanisms for reporting back injuries, with the majority using the last definition (Table 1). The manner in which outcomes were expressed related to study designs, which included two case-control studies, nine prospective (three of which were interventions), and two cross-sectional studies. Outcomes were generally expressed as rates; for three, odds ratios were utilized, one study expressed outcomes as relative risks, and one study used duration of sick leave related to back problems. In most cases, covariates were not addressed in analyses of exposure measures and outcomes: only three conducted multivariate statistical analyses (Hoogendoorn *et al.* 2002;

Table 2. Epidemiologic studies of back disorder utilizing biomechanical measures of compressive forces to the spine

Author	Measure of exposure	Exposure/outcome*
Herrin *et al.* 1986	Peak compressive load at L5/S1 Disc (BCMax)	BCMax (lbs) — Back injury rate <1000 — 6 1000-1500 — 109 >1500 — 12
Punnett *et al.* 1991	Mean peak compressive force at L5/S1 disc	Cases: 1,915 Newtons Controls: 1,871
Garg and Owen, 1992	Mean compressive force at L5/S1 disc	Force (N) — Back injury rate Pre-interven.: 4,751 — 83 Post- 1,964 — 47
Wickstrom *et al.* 1993	% of time exceeding disc pressure (>1500 Newtons)	% time exceeding pressure — Days sick leave/person-yr pre-interven: 19 — 3.1 post: 11 — 1.9
Kerr *et al.* 2001	Mean peak compressive force at L4/L5 disc	Cases: 3,402 Newtons Controls: 2,744
	Cumulative force at L4/L5 Disc	Compressive Force — Odds Ratio >4.6x10^{6} N-s/shift — 2.0
Stuebbe *et al.* 2002	Cumulative daily spinal Compressive forces (kN)	Job — Force — Back injury rate Glue-line opr: 133 — 10 Glue-line QPA: 146 — 15 Press opr: 177 — 11 Carton stripper: 200 — 33

* See Table 1 for definitions

Table 3. Epidemiologic studies of back disorder utilizing measures of lifting (mass, frequency, duration)

Authors	Exposure/outcome*						
Chaffin and Park, 1973	Weight of load in LSR position (lbs)	Low back incidence rate	Frequency of LSR lifts/day	Low back incidence rate			
	0-20	0.4	0-50	1.5			
	20-40	1.5	50-100	0.6			
	40-60	0.8	100-150	0.7			
	60-80	3.4	150+	2.5			
	80+	0.8					
Ljungberg *et al.* 1989	Job	Group ave. lifts/hr	Cumulative force per hour (N/hr)	Time per lift(s)	Time for lifts (s/h)	% of time lifting	Back injury rate+
	Nursing ass't, traditional	30	2,880	10.5	309	8.6	5.0
	" " modern	14	1,660	4.8	68	1.9	2.5
	Warehouse grocery	100	11,070	2.6	259	7.2	0.7
	" fresh food	78	9,930	2.4	187	5.2	1.5
Punnett *et al.* 1991	Mass lifted	Adjusted Odds Ratio					
	≥44.5 Newtons	2.2					
Garg and Owen, 1992	Hand force (sic) (Newtons)		Back injury rate				
	Pre-intervention: 312		83				
	Post intervention: 122		47				

Table 3, continued. Epidemiologic studies of back disorder utilizing measures of lifting (mass, frequency, duration)

Authors	Exposure/outcome*			
Marras *et al.* 1995	Injury rate category	Low (0/yr)	Medium (median 6/yr)	High (median 16/yr)
	Lift rate/hr	118.8	196.3	225.6
	Ave. weight handled (N)	29.3	75.0	88.4
	Max. weight handled (N)	37.2	98.2	113.7
Kerr *et al.* 2001	Peak hand force (sic)	Adjusted Odds Ratio for back injuries		
	17 kg	1.9		
Hoogendoorn *et al.* 2002	No. lifts/working day	Relative Risk (crude) for Sickness/absence>3 days		Back injury rate‡
	0	1.0		4.2
	never≥10 kg/day	2.3		8.0
	never≥25 kg/day	2.8		10.4
	1-15 times≥25 kg/day	3.6		15.0
	>15 times≥25 kg/day	3.8		15.6
Sesek *et al.* 2003	Weight lifted/day	Odds Ratio for low back injury		
	≥8 kg at least once	2.1		
	≥18 kg >5 times	2.2		
	lift≥4.5 kg >500 times	1.6		
	lift≥4.5 kg >1000 times	1.7		
	total weight lifted/day (>9000 kg)	2.4		

Table 3, continued. Epidemiologic studies of back disorder utilizing measures of lifting (mass, frequency, duration)

Authors		Exposure/outcome*	
		No. lifts/day>0 kg	Ave. duration sickness/absence due to back problems (days)
Luijsterburg *et al.* 2005			
	Intervention:baseline	1,075	3.2
	“ follow-up	962	0.2
	Controls: baseline	1,137	3.1
	“ follow-up	826	2.9

* See Table 1 for definitions
\+ Estimated annual rates calculated per 100 employees
‡ Estimated crude annual rates calculated per 100 employees

Kerr *et al.*, 2001; and; Punnett *et al*. 1991). Others restricted study populations by sex, and a number examined relationships stratifying by job group.

The study populations were largely industrial, including automobile, paperboard packaging, sheet metal and mixed industrial groups that did a significant amount of manual material handling work. Two studies included health care workers; another examined bricklayers. Exposure measures fell into four major categories: 1) compressive forces on the spine, 2) lifting frequency, mass, or duration, 3) lifting ratios or indices, and 4) measures of posture.

3.1. Compressive forces on the spine

Table 2 shows information from studies that utilized measures of compressive forces on the spine (n=6). Study designs, exposure measures, and outcomes varied, although some direct comparisons can be made. Garg and Owen (1992) examined mean compressive spinal force at the L5/S1disc, calculated using a three-dimensional static biomechanical model (Garg and Chaffin, 1975) and a prospective design. Lower rates for back injuries and lost or restricted work days were associated with lower compressive forces (Table 2). Using a similar prospective design, Herrin, et al (1986) found that peak compressive force at the L5/S1 disc varied by force category, with the highest back injury rated in the 1000-1500 lb. range. Lost or restricted work days followed a similar pattern. The two case-control studies presented mean peak spinal compressive force at the L5/S1 disc (Punnett *et al*. 1991) and L4/L5 disc (Kerr *et al.* 2001) for cases and controls; both showed higher compressive forces for cases. In these two studies, methods used to estimate compressive force included a two-dimensional quasi-dynamic biomechanical model (Kerr *et al.* 2001; Neumann, 1999) and a three-dimensional biomechanical strength model (Chaffin and Andersson, 1991; Punnett *et al*. 1991). Stuebbe *et al*. (2002) found generally increasing back injury rates within increasing cumulative spinal compression, calculated using a biomechanical model developed at the U.S. University of Miami (1986). Kerr, *et al.* also examined the relationship between higher cumulative lumbar disc compression (based on a cut-point derived from the interquartile range 4.6×10^6 newtons per shift), calculating an odds ratio of 2.0 (95% confidence interval 1.2, 3.6) after adjusting for covariates. Wickstrom *et al*. (1993) found increasing rates of sick leave days with increasing percentage of time exceeding a spinal disc pressure (sic) of 1500 N (no sick leaves were observed when a higher, 3000 N, cut-off was utilized); disc pressures (sic) were estimated using a two-dimensional biomechanical model created at the University of Michigan (1986). Thus, although outcomes and expressions of spinal compression force varied, results were consistent in showing positive associations between back disorder and mean, peak, and cumulative compressive forces.

3.2. Lifting frequency, mass, or duration

Nine investigations utilized biomechanical measures of lifting, including frequency, mass, duration, or various combinations of the three (Table 3). Six authors examined lifting frequency in some manner, with five finding little evidence of association between exposures and back outcomes (Chaffin and Park, 1973; Hoogendoorn *et al.* 2002; Ljungberg *et al*. 1989; Luijsterberg *et al*. 2005; Sesek *et al.* 2003); Chaffin and Park (1973) may have observed an effect threshold at 150 lifts or more per day. Marras *et al.* (1995) observed increased risk of back injury with increasing lifting frequency. Of seven authors that examined effects of mass, most found an association between weight lifted and increased back injury (Garg and Owen, 1992; Kerr *et al*. 2001; Punnett et al. 1991; Marras *et al*. 1995; Sesek *et al*. 2003). In two studies, no relationships

Table 4. Epidemiologic studies of back disorder utilizing lifting ratios

Authors	Lifting Ratio	Exposure	Back outcome*
Chaffin and Park, 1973	Lifting strength rating (max. load/ Lifting strength of large strong male)	LSR	Back incidence rate
		0-0.2	0.8
		0.2-0.5	1.8
		0.5-0.8	1.9
		0.8-1.0+	3.8
Liles *et al.* 1984	Job severity index (ratio of job demands to lifting capacity of worker)	JSI	Back injury rate
		0-2.9	3.8
		0.30-0.57	1.9
		0.57-0.81	7.7
		0.81-1.07	3.7
		1.09-1.42	0.0
		1.42 -1.76	15.0
		1.77-2.09	17.0
		2.10-2.61	18.9
		2.62-3.65	18.8
		3.66+	17.1
Herrin *et al.* 1986	Lifting strength ratio (ratio of max. load to acceptable weight for average person performing lifting task)	LSR	Back incidence rate
		<0.5	7
		0.5-1.0	5
		1.0-1.5	10
		>1.5	14

Table 4, continued. Epidemiologic studies of back disorder utilizing lifting ratios

Authors	Lifting Ratio	Exposure Back outcome*		
Marras *et al.* 1993	Index from lumbar motion monitor measures: lift rate, ave. twisting velocity, max. moment, max. sagittal flexion, max. lateral velocity	High risk of low back disorder: Odds Ratio=10.7		
Marras *et al.* 1999	Revised NIOSH Lifting Equation	Risk of back pain	RNLE category	% in category
		Low	<1	55
			1-3	22
			>3	23
		Medium	<1	11
			1-3	21
			>3	68
		High	<1	8
			1-3	19
			>3	73
Sesek *et al.* 2003	Revised NIOSH Lifting Equation	Lifting Index	Back injury Odds ratio	
		1.0	2.1	
		3.0	4.0	

* See Table 1 for back outcome definition

Table 5. Epidemiologic studies of back disorder utilizing measures of posture

Authors	Exposure/Outcome*			
Punnett *et al.* 1991	Back posture (ever)	Unadjusted Odds Ratio	Dose-response with duration	
	<20^o bending or twisting	0		
	mild forward flexion (21-45^o)	4.9	Yes	
	severe forward flexion (>45^o)	5.7	Yes	
	lateral twisting or bending (>20^o)	5.9	No	
Marras *et al.* 1995		Risk of back injury		
		Low	Medium	High
	Max. extension position (^{o})	-10.3	-6.2	-8.0
	Max. flexion position (^{o})	10.4	17.6	20.0
	Range of motion (^{o})	23.8	30.0	34.0
	Ave. velocity (^{o}/s)	6.6	11.4	12.4
	Max. velocity (^{o}/s)	38.7	53.7	59.0
	Max. acceleration ($^o/s^2$)	226	307	340
	Max. deceleration ($^o/s^2$)	-83.3	-79.7	-95.2

Study	Exposure		Outcome
Hoogendoorn *et al.* 2002	% of working time trunk flexed ≥30°		Sickness absence>3 days, crude Relative Risk
	≤5		1.0
	5-10		1.8
	10-15		2.8
	15-20		4.0
	>20		3.0
	% of working time trunk rotated ≥30°		Sickness absence>3 days, crude Relative Risk
	≤5		1.0
	5-10		2.9
	>10		1.7
Stuebbe *et al.* 2002		Time spent with back extension, flexion, or lateral bending >15° (average)	Back injury rate
	Press operator	42	11
	Glue line operator	50	10
	Glue line QPA	57	15
	Carton stripper	59	33

Table 5, continued. Epidemiologic studies of back disorder utilizing measures of posture

Authors	Exposure/Outcome*	Intervention		Control	
		baseline	follow-up	baseline	follow-up
Luijsterburg *et al.* 2005	% of day				
	back>30^{o} flexion	60	40	62	53
	back >60^{o} flexion	38	21	41	35
		Intervention		Control	
		baseline	follow-up	baseline	follow-up
	minutes duration				
	back>30^{o} flexion	203	171	220	228
	back >60^{o} flexion	127	87	146	151
	Ave. duration sickness/absence due to back problems (days)	3.2	0.2	3.1	2.9

* See Table 1 for definitions

were observed (Chaffin and Park, 1973; Ljungberg *et al*. 1989). Only one author examined effects of duration of exposure, finding no association between back injury and percent of time spent lifting or total time spent in lifts (Ljungberg *et al.* 1989). However, there was some indication that time per lift was related to back injury likelihood. Thus, overall there was little evidence that lifting frequency or duration were strongly associated with back outcomes in these studies, but mass lifted did appear to have an association in the majority of studies that examined this variable.

3.3. Lifting ratios

Five investigations utilized lifting ratios as exposure measures (Table 4). These were calculated indices that included variables related to the lifted object and its relationship to the worker (Revised NIOSH Lifting Equation, or RNLE) or to an acceptable weight ((Job Severity Index (JSI) and Lifting Strength Rating or Ratio (LSR)). Two studies using LSRs were very similar and found increasing back injury rates with increasing LSR (Chaffin and Park, 1973); Herrin *et al.* 1986). Liles *et al.* (1984), used a similar index, the JSI, and found generally higher back injury rates at higher index levels; there appeared to be a threshold effect where markedly higher injury rates were observed (Table 4). The two studies that utilized the RLNE had similar, unusual, study designs where job, rather than the individual, was used as the unit of analysis (Marras *et al*. 1999; Sesek *et al.* 2003). For both studies, statistically significant increases in ORs were observed with higher lifting indices. An additional study by Marras *et al*. (1995) created a composite variable from five individual measures of lifting rate and posture, finding an Odds Ratio of 10.7 for high risk of back disorder (Table 4). Once again, studies using lifting indices were disparate is some respects, but found consistent positive associations between exposures and back injury outcomes.

3.4. Measures of posture

Six studies examined measures of posture (Table 5). Punnett *et al*. (1991) utilized video recordings to characterize jobs with regard to forward flexion and lateral bending or twisting, defining categories in degrees. Hoogendoorn *et al*. (2002) used similar methods to estimate trunk flexion and rotation, but created different cut-points for severity (in degrees) and duration categories. A study by Luijsterburg *et al.* (2005) examined back outcomes using videotaping and trunk flexion categories similar to those created by Hoogendoorn (classifying by degrees and duration). Stuebbe *et al*. (2002) also used videotaping and direct observation methods to characterize postures in packaging plant workers, calculating per cent of time spent in non-neutral postures (trunk flexion, extension, lateral bending and rotation greater than 15 degrees). Although outcome measures were expressed differently and posture categories had different cut-points, all four studies found associations between back injuries and posture exposure levels, with several dose-response relationships demonstrated. Ljungberg *et al.* (1989) utilized the Ovako Working Posture Analysis System (OWAS) (Karhu *et al.* 1977) to describe work postures for a subset of the nurse study participants, assigning scores to observed postures (e.g., subject lifting or carrying, posture with static components), but did not calculate relationships with back outcome measures. Marras *et al.* (1995) used considerably different methodology to examine relationships between three-dimensional posture measures (trunk flexion, extension in two planes, and twisting, measuring motions in degrees, along with velocities and accelerations) using the Lumbar Motion Monitor (LMM). Of the individual motions measured, sagittal velocity was most strongly associated with back injury risk (OR=3.3); however, a measure of the combination of five variables (maximum load moment, maximum lateral velocity, average twisting velocity, lifting frequency and maximal sagittal trunk angle) demonstrated the strongest association with back injury (OR=10.7). Thus, all five studies that examined relationships showed consistent associations between posture measures and back outcomes.

3.5. Combining study results

Many of the studies examined effects of lifting frequency and mass; however, there was little evidence of an association between lifting frequency levels and likelihood of back injury. Although seven studies examined effects of mass, with five showing associations between weight lifted and back outcomes, none of these used exposure and outcome definitions that were comparable enough to combine information from the investigations.

Only three groups of studies used similar exposure/outcome methodologies, with two studies in each group: 1) the two case-control studies which presented mean peak compressive forces at the L4/L5 (Kerr *et al.* 2001) and L5/S1 (Punnett *et al.* 1991) disc for cases and controls (assuming that forces at these two disc levels are comparable), 2) the Marras and Sesek studies that utilized the RNLE, and 3) the Chaffin and Park and Herrin studies which used LSR categories. It was not feasible to combine results from the case-control studies in a quantitative way because this exposure measure, as defined, was not used in the statistical analyses presented. The two studies using the RNLE were not mathematically combinable because calculations were done using job, rather than individual, as the unit of analysis. The remaining two studies might be combined, making several assumptions. Results are not presented here because outcomes were expressed as rate categories, which are not easily generalizable to exposure-response calculations that might be carried out in other workplaces.

3.6. Example: Internal Rate of Return on a hypothetical ergonomic intervention

A sample calculation of the internal rate of return (IRR) on a hypothetical ergonomic investment was made using data from one study identified in this systematic review (Chaffin and Park, 1973). The IRR is a common method used by business for calculating the investment worthiness of alternative capital investment options (Graham and Harvey, 2001). The investment was an adjustable-height table (Roto-Max Work Positioner, Lift Products, Inc., ElmGrove, WI) for presenting 4 kg parts to a worker during a manual materials handling task. Prior to the intervention, the location of the object to be lifted was 65 cm anterior to a point midway between the ankles and 17 cm off the floor. The lift table is assumed to change this location to 27 cm anterior and 92 cm vertical distance from the worker.

The IRR on the lift table investment was computed by determining the discount rate that makes the net present value of the investment costs equal to the net present value of expected cost savings. In short, this is determining the rate, r, such that

$$NPV\ (r) = \sum_{t=0}^{T} \frac{1}{(1+r)^t} \left(B_t^{WC} + B_t^{replacement\ labor} - C_t \right) = 0$$

where B_t^{WC} is the workers' compensation cost savings in year t resulting from the lift table investment, $B_t^{replacement\ labor}$ is the costs savings from a reduction in labor required to fill-in for injured workers in year t, and C_t is the cost of the lift-table in year t, and T is the planning horizon. The workers' compensation cost savings benefit, B_t^{WC}, is

$$B_t^{WC} = P \times N \times C$$

where P is the reduction in injury probability, N is the number of employees exposed to the job, and C is the average cost per claim per year (which includes medical costs and partial wage replacement). Average cost per claim includes worker's compensation cost as if the employer is self-insured. The reduction in replacement labor cost, $B_t^{replacement\ labor}$, was calculated using

$$B_t^{replacement\ labor} = 8 \times D \times W \times P \times N$$

where D is the mean number of days off work per case and W and is cost of an hour of replacement labor.

P was estimated from the exposure-response relationship reported by Chaffin and Park (1973). Average LBP claims cost and lost time were estimated to be \$7,541 (C) and 107 days (D), respectively, based on workers' compensation data from Washington state (Silverstein and Kalat, 2002). Employees were assumed to be paid \$10 per hour, with benefits assumed to be an additional 30% of this rate ($W = \$13/hr$). We assumed there were three shifts, so three employees were exposed to this workstation.

Other assumptions that were made: the lift costs \$3,325 and has no salvage value at the end of its useful life. The useful life of the lift is 10 years; the annual maintenance cost is 5% of the purchase price; a tax rate of 35% was used and the lift was depreciated using the straight-line method; purchase cost, annual maintenance, and salvage value were included in the analysis. No changes in productivity resulted from the intervention.

The after-tax IRR resulting from the hypothetical investment in a lift table was 20%. This estimate was based on an estimated reduction in back injury rate. Using the methodology of Chaffin and Park (1973) for estimating exposure, the pre- and post-intervention lifting strength ratio is 0.36 and 0.14, respectively. Using the injury rate data results of that study (Table 2), the expected reduction in injury rate would be one case per 1000 person-weeks. Using 2 000 hours per year per full-time employee, this estimate was converted to a reduction in the probability of LBP per employee per year (0.05). Since three people were exposed to this job, the total reduction in the expected number of cases per year is 0.15.

The annual expected cost savings resulting from preventing injuries (B_t^{WC}) was \$377. The reduction in replacement labor cost per year ($B_t^{replacement\ labor}$) was \$668. After maintenance costs, depreciation, and taxes were accounted for, the annual savings was \$687.

4. Discussion

Although many publications examining relationships between occupational exposures and back disorders were identified in the literature, very few met inclusion criteria for this study. The 13 investigations described here varied in terms of study design, methods, and definitions used for

Table 6. Comparison of exposure assessment methods: ease of use for cost-benefit analysis of ergonomic interventions

Method*	Exposure measured	cost ($ U.S.)	easy to use in field	output data can be used for cost modeling	output data are easy to transfer to cost models
Univ. of Michigan 3D SSPP	spinal compression	$1 345	yes	yes	yes
LMM	postures spinal compression dynamic lifting	$24 995	no	no	no
LSR	lifting strength ratio	free (nomogram)	yes	yes	yes
RNLE	lifting index	free (downloadable)	yes	yes	yes
OWAS	postures	free (downloadable)	no	yes	no

* See Table 1 for descriptive references

exposure assessment, but were consistent with other reviews in showing clear associations between occupational posture and lifting measures and back outcomes (Bernard, 1997). Evidence suggests that the 13 studies are more or less representative of typical workplaces. For example, exposure levels for compressive forces to the spine identified in this study (Table 2) appear to be typical of exposures found in health care facility data available in other published literature (Daynard *et al.* 2001; Kumar and Narayan, 2005, Lavender *et al.* 2000; Marras *et al.*1999; Skotte, 2001, Winkelmolen *et al*. 1994). Similarly, back disorder rates shown in most of the 13 studies which calculated rates as outcomes mirrored those described in the Washington State workers' compensation data (Silverstein and Kalat, 2002).

The origin of work-related back disorder is recognized as being multifactorial. Risk factors encompass both psychosocial and physical workplace stressors, with the latter including "heavy work", lifting, awkward postures, and vibration (Bernard, 1997). In this review of effects of physical risk factors, exposure definitions varied significantly, but tended to fall into four main categories: compressive forces to the back, lifting measures, lifting ratios and posture assessments. A question that arises is whether any one method of measuring exposures to back stressors is superior to others, in terms of its strength of association with back outcomes, accuracy, reliability, and ease of use in field situations. Compressive force to the spine, for example, has long been used as a biomechanical measure of back stress (Granata and Marras, 1991; Dempsey 1998). A recent meta-analysis suggested that cumulative spinal compressive force is a good predictor for low back pain (Waters *et al.* 2006).

A number of studies have addressed the issue by comparing other biomechanical methods in workplace environments. Three exposure assessment methods utilized in this paper have been so evaluated: the University of Michigan's 3-Dimensional Static Strength Prediction Program (3D SSPP), the LMM, and the RNLE (Lavender *et al.* 1999; Marklin and Wilzbacher, 1999; Mirka *et al.* 2000; Waters *et al.* 1998). These field investigations suggested that no single method is best, but instead, that the exposure assessment method should be selected based on characteristics of the job and workplace to be evaluated. For example, symmetric static tasks can be analysed using a 2-dimensional system, asymmetric tasks require a 3-D system, and dynamic or highly individual job movements might require the LMM. Two-D and 3-D analysis systems are hypothesized to be better used when the exposure is thought to lead to acute back disorder, while LMM analysis is based more on a cumulative model of exposure-response. For the objectives of this paper, ease of use in field situations, simple transfer of output data to cost equations, and cost itself were of particular importance. Table 6 summarizes strengths and weaknesses of several exposure assessment methods. Safety practitioners can use this information to select a biomechanical method that is specifically appropriate for their particular workplace situation and proposed intervention.

Results from this review focused primarily on lifting as a major biomechanical risk factor for back disorder. Another well-recognized physical workplace stressor is awkward postures, which were briefly addressed here. Many biomechanical methods have been developed to evaluate these, including pencil and paper evaluations, checklists, direct observation, videotaping, and three-dimensional computer-assisted systems developed for laboratory use (Li and Buckle, 1999). Although posture analysis is labor-intensive and thus fairly expensive to use in work settings, this approach could also be used to demonstrate cost savings resulting from exposure reduction.

We have identified studies that can be used in cost-benefit analysis models for ergonomic interventions to prevent low back disorder. However, the large heterogeneity of study designs made it impossible to perform a meta-analysis to generate an overall estimate of the exposure-response relationship. Instead, cost-benefit analysis models could only be based on individual studies, and we have provided a framework for selecting studies based on practical considerations (Table 6). The IRR calculations carried out here demonstrate cost reductions that might be realized by implementing specific interventions that decrease biomechanical exposures. The variables required are largely available to company safety personnel; other input variables can be based on reasonable estimates (e.g., useful life of the intervention; salvage estimate). Workers' compensation costs can be estimated based on the company's own claim costs or published data. Advantages of using published workers' compensation data include stability in rates and costs observed, since they are based on large numbers. For example, the Washington State data have been shown to be representative of the U.S. as a whole (Volinn *et al*. 2005). Some work environments might have injury rates that differ significantly from the norm. In this situation, use of company-specific data would be preferable so that cost reduction estimates are as relevant as possible. Methods other than IRR can be used to calculate cost-benefit measures, as well, including computation of net present value or pay-back period. The latter can be estimated using worksheets that accompany a text by Oxenburgh *et al.* (2004) (although pay-back period is not commonly used in corporate finance).

In summary, data from published literature have demonstrated clear relationships between workplace biomechanical risk factors and economically-defined back disorder outcomes. The calculations provided here as an example can be used by plant personnel to calculate cost reductions related to proposed workplace interventions. More simple or complex approaches might be used, depending on available data and needs.

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