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Cumulative spinal loading exposure methods for manual material handling tasks. Part 1: is cumulative spinal loading associated with lower back disorders?

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Objective: To critically appraise the observational studies linking cumulative spinal loading and lower back disorders (LBD) among workers engaged in manual material handling and to explore the association between cumulative spinal loading and LBD through a meta-analysis of papers reported in the published literature.
Background: Although studies have indicated a definitive relationship between long-term exposure to manual materials handling and LBD, little is generally known about the validity of the cumulative exposure assessment methods used for predicting the risk of LBD.
Methods: A comprehensive electronic search on the subject was conducted. The articles found from the search were critically appraised from an epidemiological standpoint. The strengths and weaknesses of the studies were documented. A quantitative assessment was performed for the meta-analysis estimate using the fixed-effect and random-effects (Dersimonian and Laird method) models. The assessments were conducted in two ways: with a standard approach that does not consider study quality and with a modified method that allows weighting scores to be calculated based on the rating of the quality of each study.
Results: The electronic search resulted in identification of four epidemiological papers, three of which provided sufficient information for an assessment of epidemiological quality and two of which provided sufficient data to conduct a meta-analysis. The results showed that the methodological quality of the studies ranged from poor to marginal. Without considering the overall study quality for the exposure data, (1) there were substantial differences between the three studies that were rated for epidemiological quality as evidenced by the significant heterogeneity testing at the 10% level and (2) the difference in the mean exposure values between the study and control groups (i.e. summary mean difference) was significant at the 5% level for both the fixed-effect and random-effects models. After accounting for overall study quality, the heterogeneity was reduced but still significant at the 10% level and the summary mean difference was greater than that without the quality score. The meta-odds ratio for LBD outcomes was 1.66 (95% confidence interval using quality scores = 1.46–1.89).

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Conclusions: The preliminary findings suggest that there likely is an association between cumulative spinal loading and LBD. Further, there are considerable differences among the studies in terms of exposure assessment techniques. A subsequent paper (Part II of this research) provides an in-depth analysis of cumulative spinal loading exposure methods and discusses critical issues related to their reliability and validity for estimating force distribution and practicality for field measurement.

Keywords: Lower back disorders; Manual material handling; Cumulative spinal loading

1. Introduction

Work-related musculoskeletal disorders (MSD), such as lower back disorders (LBD), are a common occupational health problem in industrialized countries, accounting for more than one-third of all the occupational injuries and illness in the US (Bureau of Labor Statistics 2001). Leigh *et al.* (1997) estimated the total cost of occupational low back pain in the US to be $49.2 billion in 1992 and Murphy and Volinn (1999) estimated the costs for workers' compensation claims alone for LBD in the US to be $8.8 billion in 1995. It is believed that work-related LBDs are triggered by a complex process which involves the interaction of physical work factors (e.g. biomechanical factors), non-physical work factors (e.g. psychosocial stress and work organization factors) and individual characteristics (e.g. prior medical history, strength capabilities and personality traits) (NIOSH 1997, 2001, National Research Council and Institute of Medicine 2001). Other non-physical factors, such as perceived effort and work satisfaction or dissatisfaction, may also play a role in the development and/or reporting of LBD (Bigos *et al.* 1991, Kerr *et al.* 2001).

The assessment of health risk for manual materials handling (MMH) hazards has generally focused on the analysis of a single event or condition that may precipitate an acute back injury. Usually the analyst considers the effects of the peak exposure to a single risk factor. In recent years, awareness of the role biomechanical stress plays in the cumulative pathogenesis of lower back disorders has led to attempts to quantify the effects of repeated or cumulative physical loading associated with MMH (Keyserling *et al.* 1987, Kumar 1990, Seidler *et al.* 2001, Stuebbe *et al.* 2002). Clinical studies have demonstrated that repeated exposure to loads well below the threshold for causing traumatic, instantaneous injury can result in the eventual fatigue failure of the vertebral endplate (Brinckmann *et al.* 1998). Adverse effects of repetitive loading on spinal structures have been shown in *in-vitro* studies (Adams and Hutton 1982, Hansson *et al.* 1987, Callaghan and McGill 2001) and radiographic investigations (Brinckmann *et al.* 1998).) The time-varying load-tolerance model shown in figure 1 has previously been proposed (McGill 1997, Marras 1999). As can be seen in figure 1, the traditional model of biomechanical risk assumes a constant tissue tolerance level, whereas the time-varying load tolerance model assumes that the tissue tolerance decreases due to repeated loading, thereby decreasing the safety margin and lowering the load threshold for back injury. This response and the rate of decrease can be attributed to the accumulated loading a tissue has

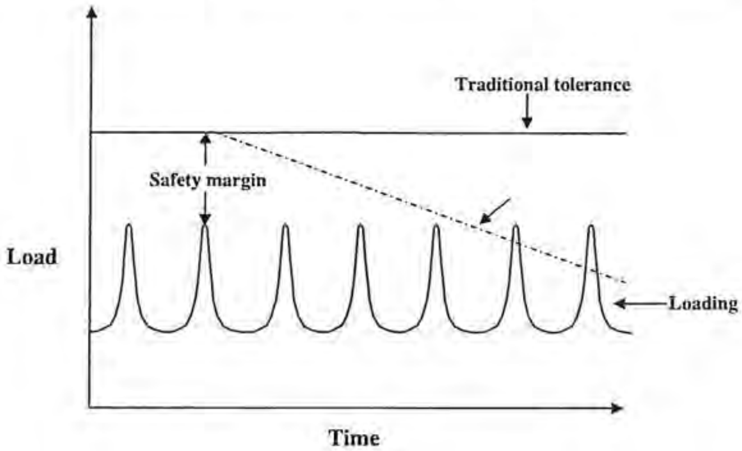

Figure 1. Traditional versus time-varying load-tolerance model.

experienced and the way the force, repetition and postural factors have interacted during exposure. Since working life is typically comprised of a complex set of individual and interactive risk factors that act repeatedly, over an extended period of time, a methodology to assess the cumulative, aggregate risk incurred by the biological system may be helpful in predicting the overall risk of LBD due to repeated spinal loading.

To date, MMH, such as lifting, pushing and pulling, has been identified as the most probable cause of work-related LBD in the workplace. The biomechanical loading associated with extended exposure to static awkward back postures has also been implicated as a potential risk factor for LBD. Presently, most exposure assessment methods reported in the published literature have focused on the evaluation of the stressfulness of manual lifting tasks based on the assessment of biomechanical exposure variables (Chaffin and Park 1973, Ayoub *et al.* 1983, Marras *et al.* 1993, Kee and Karwowski 2001); psychophysical demands (Snook *et al.* 1978) or physiological tolerance limits (Garg *et al.* 1978, Genaidy and Asfour 1989, Asfour *et al.* 1991); or a combination of these factors as employed in the Revised NIOSH Lifting Equation (Waters *et al.* 1993, Karwowski *et al.* 1999). For the most part, these assessment methods have not considered the cumulative aspects of MMH stresses. Cumulative exposure assessment methods, however, are now emerging as potential tools to quantify the 'dose' parameter in the prediction of LBD health risk in occupational epidemiological studies. Recently, the role of cumulative physical workload as a risk factor for lumbar spine disorders has been the subject of increased focus (e.g. Seidler *et al.* 2001, 2003, Callaghan 2004). The goals of this research are to appraise the current scientific methods for estimating cumulative spinal loading resulting from occupational exposure to MMH and static back postures and to determine whether cumulative spinal loading is associated with lower back disorders.

This paper reports on a critical appraisal of epidemiological studies linking cumulative spinal loading to LBD and a meta-analysis conducted to determine the capability of cumulative spinal loading measures to estimate the association between cumulative load and lower back outcomes. A subsequent paper closely examines issues related to the use of cumulative spinal loading as an exposure assessment method for epidemiological research, including validity, reliability and practicality for field measurement. It is recognized that some studies published in the area were not designed to be epidemiological studies. However, in order to advance the field a critical assessment of all papers is necessary to develop understanding of the state of affairs and future directions.

2. Methods

2.1. *Search strategy and study identification/selection*

An electronic search was conducted using the following databases: Medline (Ovid Web, from 1966), OSHLINE, NIOSHTIC, Ergonomics Abstracts and SCI expanded database. An initial search with a search strategy that specifically targeted cumulative spinal exposure yielded relatively few studies. To avoid missing any relevant studies, one chose to err on the side of over-inclusion during the search. Consequently, search terms were increased to include lifting, low back pain, lower back pain, biomechanics, cumulative load, cumulative exposure, spinal loading, compressive loading, shear loading, compressive force, shear force, frequency of lifting, duration of lifting, manual handling, carrying, pulling and pushing. As a result, numerous studies were identified in the expanded search, many of which were not subsequently found to be relevant with regard to cumulative spinal loading. The research was restricted to peer-reviewed literature in the English language up to 1 April 2004. In addition, there was no restriction on study design.

Selection of studies for inclusion in the review was completed through a multi-stage process. The first stage involved screening the papers by assessing titles and abstracts to determine whether or not it was likely the studies actually addressed the issue of cumulative load. Initially, an investigator (SY) on the research team reviewed all citations returned from the search engines employed. If, given the information available, it was determined that the article definitely did not address cumulative load, it was excluded from the review, otherwise the full text of the article was obtained and reviewed. Following the review, if the investigator deemed that the article adequately addressed cumulative load, it was formally abstracted and included for consideration in the paper. The final list was further evaluated by three members of the research team (TW, AG, JC). Three additional articles were later identified and added to the overall. The final list contained 13 articles that met the original selection criteria.

2.2. *Quality assessment*

Each observational study was formally evaluated using an epidemiological appraisal checklist. Table 1 includes the elements of critical appraisal and items linked with every element used in evaluating each study. In total, there were 43 items categorized under five elements, namely, (1) reporting, (2) subject selection, (3) measurement or observation quality, (4) data analysis and (5) generalization of results (Genaidy and LeMasters 2005). The score for each item was determined as follows: yes (2 points), partial (1 point), no or unable to determine (0 point). The final score for each element (e.g. evidence reporting) was taken as the average of the values recorded for each item.

Table 1. Elements of critical epidemiological appraisal.

Element	Items	
Generalization		Application of study results to eligible population, application of study results to other relevant groups
Data analysis	Covariates/confounders	Disease/symptom history, individual variables, environment variables
	Other	Follow-up time adequacy, adjustment for different lengths of time, analysis by level of exposure, analysis by level sub-groups
Observation bias	Observation period	Comparability of observation period among different groups
	Outcome	Reliability and validity, methods' comparability
	Blind measurement	Observers, subjects
	Exposure	Validity and reliability, methods' comparability, timing of assessment
Subject selection		Group comparability, participation rate, time period, dropouts
Evidence reporting		Hypothesis, exposure, outcome, study design, study population, covariates/confounders, statistical tests and analysis strategies, main results

Two members of the research team (AG and HB) conducted the critical appraisal independently. In a follow-up session, the results of the evaluations were compared and areas of disagreement were discussed until a consensus was achieved.

Following the epidemiological appraisal, a summary of evidence was documented for each study in terms of exposure, outcome, study design, study population and main result. In addition, the results of the epidemiological appraisal were summarized graphically for each study in terms of the five major elements, as well as sub-scales within the observation quality and data analysis scales.

2.3. *Data extraction*

A member of the research team (AG) extracted exposure and outcome data from the original articles for all groups. In addition, the number of subjects within the study was also documented. For the purpose of meta-analysis, assumptions were made to collect the necessary information and will be reported in the results section.

2.4. *Statistical methods*

In order to calculate the mean difference in exposure between the study and control groups (summary mean difference), both the fixed-effect and random-effects models (Dersimonian and Laird method) have been used. According to Elwood (2000), both types of models yield similar results when there is no heterogeneity between studies. However, where there is heterogeneity, the random-effects model may give substantially different results. It gives a greater importance to the smaller studies in the set. The meta-risk estimate for outcome data was also calculated using the fixed-effect and random-effects models. The general variance method was employed to calculate the meta-analysis statistics by using the confidence interval techniques. The weighting factor for the random-effects model was computed using the Dersimonian and Laird procedure.

Heterogeneity testing was conducted using the Q_i procedure (Petitti 2000) with the following equation for the exposure data:

$$Q = \sum_i \text{sum}\left(\text{weight}_i * (\text{mean}_i - \text{mean}_s)^2\right)$$

where weight is the inverse of variance, i is the study number, $i = 1, 2, 3$, $\text{mean}_i =$ mean difference for study i and $\text{mean}_s =$ summary mean difference; and the following equation for the outcome data:

$$Q = \sum_i \text{sum}\left(\text{weight}_i * (\ln OR_s - \ln OR_i)^2\right)$$

where weight is the inverse of variance, i is the study number, $i = 1, 2$, $\text{OR}_s =$ summary odds ration and $\text{OR}_i =$ odds ratio for study i. The variable Q has a χ^2 distribution with degrees of freedom equal to the number of studies minus one.

In the calculation of the weights used to derive the meta-point estimates, the weight was computed for each study in two ways: (1) the inverse of the variance (i.e. of the estimated log odds for odds ratios in table 4; the variance is the square of standard deviation in table 3); and (2) the product of the inverse of the variance and the overall study quality. For each study, the overall quality was calculated as the ratio of individual quality score and sum of all study scores.

3. Results

3.1. *Overview of studies*

After the initial search and further examination of the titles, abstracts and full text of the papers, 13 articles were identified as relevant and included for review in this paper (Kumar 1990, Norman *et al.* 1998, Mientjies *et al.* 1999, Jager *et al.* 2000, Mirka *et al.* 2000, Callaghan *et al.* 2001, Daynard *et al.* 2001, Kerr *et al.* 2001, Stuebbe *et al.* 2002, Sullivan *et al.* 2002, Andrews and Callaghan 2003, Seidler *et al.* 2001, 2003). Six of these studies evaluated the association of cumulative spinal loading with lower back disorders (Kumar 1990, Norman *et al.* 1998, Kerr *et al.* 2001, Seidler *et al.* 2001, 2003, Stuebbe *et al.* 2002). Two of those six studies (Kerr *et al.* 2001, Seidler *et al.* 2003) were excluded from the epidemiological appraisal and the meta-analysis evaluation because they were based on the same data sets utilized in earlier publications from the same research group (Norman *et al.* 1998, Seidler *et al.* 2001, respectively). The remaining four studies were critically appraised based on epidemiological principles reported in the published literature (Crombie 1996, Elwood 2000).

3.2. *Epidemiologic appraisal of observational studies*

An overview of the evidence description is presented in table 2. Two studies were case-control designs (Norman *et al.* 1998, Seidler *et al.* 2001) and the two

Table 2. Summary of evidence for epidemiological studies.

Source	Exposure	Outcome	Design	Population	Main results
Seidler *et al.* (2001)	Cumulative compression dose over years of exposure before onset of lumbar spine disease (MNh)	Lumbar spine disease	Case-control	229 male cases from general practices and clinics 107 regional controls 90 controls (patients) from regional hospitals	For a lumbar dose $>9 \times 10^6$ Nh, the risk of having radiographically confirmed osteochondrosis or spondylosis of the lumbar spine was 8.5 (95% CI: 4.1–17.5)
Kumar (1990)	Daily cumulative compression and shear loads in current job (MNs)	Lower back pain	Cross-sectional	161 nursing aids 147 females 14 males	Cumulative compression and shear forces were significantly higher in institutional aides with pain compared with those without pain
Stuebbe *et al.* (2002)	Daily cumulative compression load (MNs)	OSHA recordable for back injuries	Cross-sectional	Production workers in manufacturing enterprise An estimated 110 employees	Daily cumulative compression forces were significantly associated with incidence rates of recordable injuries
Norman *et al.* (1998)	Daily cumulative compression and shear loads (MNs)	Lower back pain	Case-control	Workers in manufacturing enterprie 104 cases and 130 controls	Workers in the top 25% of loading exposure are about six times the risk of reporting lower back pain when compared with those in the bottom 25%

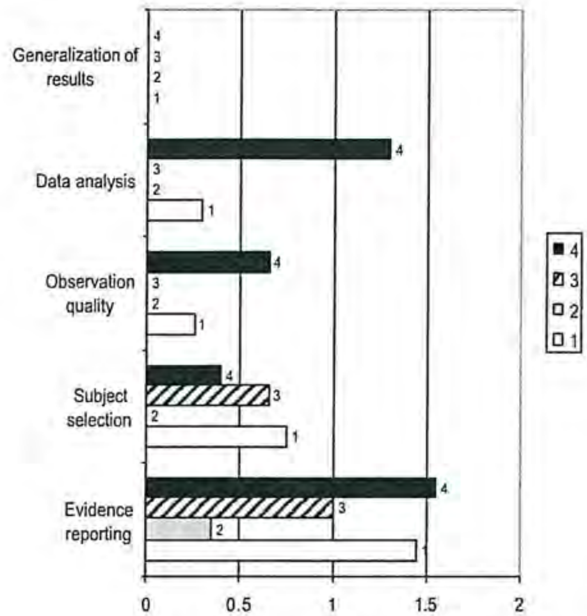

Figure 2. Critical appraisal of epidemiological studies. *Note*: (1) Norman *et al.* (1998), (2) Stuebbe *et al.* (2002), (3) Kumar (1990), (4) Seidler *et al.* (2001). *Scale Interpretation*: "Yes", 2 pts; "Partial", 1 pt; "No", 0 pt; "Unable to Determine", 0 pt.

other investigations were cross-sectional in nature (Kumar 1990, Stuebbe *et al.* 2002).

The findings of the critical appraisal linking cumulative spinal loading and lower back outcomes are displayed in figure 2 and summarized below for the four studies assessed:

(1) *Evidence reporting*: Two of the studies clearly described the various aspects of the study (Norman *et al.* 1998, Seidler *et al.* 2001). The level of reporting in other studies ranged between average (Kumar 1990) and marginal (Stuebbe *et al.* 2002). It should be pointed out that some of these studies, especially the paper by Kumar, were the first to examine cumulative load as a potential risk predictor and, therefore, were not primarily designed to be an epidemiological study, but rather as an evaluation of cumulative load methodology. Nevertheless, the results do provide positive support for the use of cumulative load as an epidemiological exposure measure and for this reason it was included in this analysis.

(2) *Subject selection*: Some studies paid more attention to subject selection and recruitment methods (Kumar 1990, Norman *et al.* 1998) than others (Seidler *et al.* 2001). One study lacked substantial information on subject selection criteria (Stuebbe *et al.* 2002).

(3) *Observation quality*: There is a 'good' potential for bias in all studies. At best, these studies scored 'marginal' adequacy (score of 0.5).

(4) *Data analysis*: One study thoroughly analysed the results by exposure and subject grouping (Seidler *et al.* 2001). Other studies were marginal in this regard.

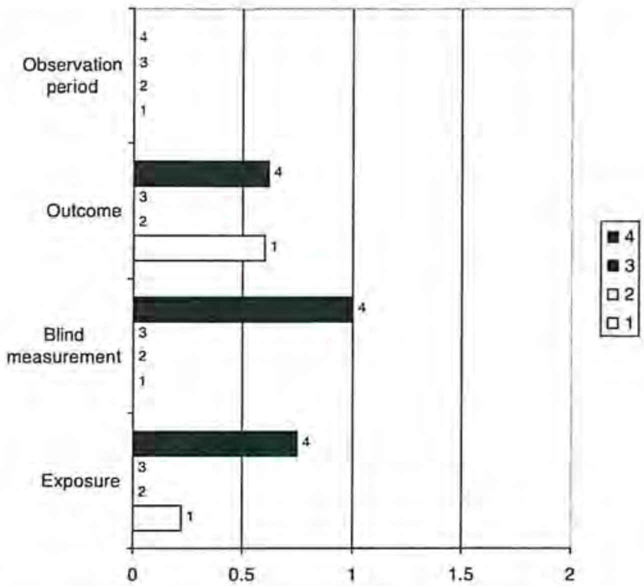

Figure 3. Critical appraisal of epidemiological studies – observation quality *Note*: (1) Norman *et al.* (1998), (2) Stuebbe *et al.* (2002), (3) Kumar (1990), (4) Seidler *et al.* (2001). *Scale Interpretation*: "Yes", 2 pts; "Partial", 1 pt; "No", 0 pt; "Unable to Determine", 0 pt.

(5) *Generalization of results*: Since all studies were either case-control or cross-sectional designs, it is difficult to determine causality. In addition, it is not clear whether the characteristics of non-participants in the eligible population were different from those who participated in the studies. To a large extent, this has limited the generalization of results to the eligible population and, subsequently, to other relevant groups.

The results of detailed critical appraisal of potential observation and data analysis bias are presented in figures 3 and 4, respectively. Figure 3 clearly demonstrates that two of the studies (Kumar 1990, Stuebbe *et al.* 2002) have a good deal of potential for observation bias. Recall, however, that the Kumar study was the first study to evaluate cumulative load and, as such, was not primarily designed for epidemiological evaluation. Other studies were somewhat better in terms of observation quality (Norman *et al.* 1998, Seidler *et al.* 2001).

Two of the studies did not account for important confounders such as psychosocial variables (Kumar 1990, Stuebbe *et al.* 2002), which has only recently been shown to be of critical importance in epidemiological studies of low back pain. The Seidler study was the best among the four investigations in dealing with potential covariates and confounders and analysing the data with respect to different levels of exposure.

In terms of overall study quality, the Seidler study achieved a score of 0.79 out of 2, followed by a score of 0.57 for Norman *et al.* (1998), then 0.33 for Kumar (1990) and 0.07 for Stuebbe *et al.* (2002). These quality rating scores are not meant to suggest that the studies were not high quality studies, only to provide a relative way of assessing them from an epidemiological standpoint.

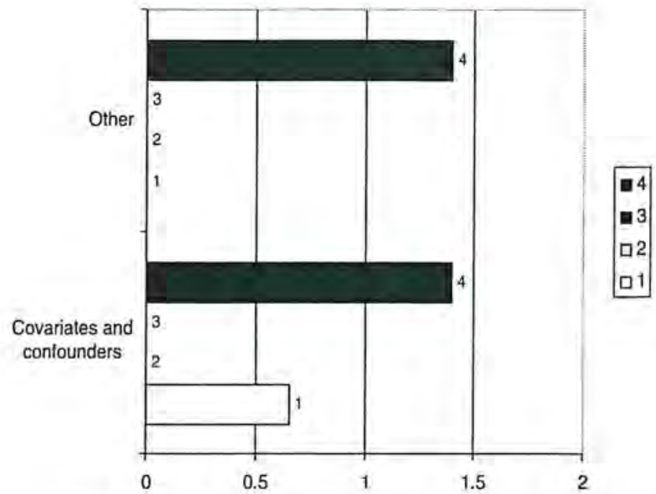

Figure 4. Critical appraisal of epidemiological studies – data analysis *Note*: (1) Norman *et al.* (1998), (2) Stuebbe *et al.* (2002), (3) Kumar (1990), (4) Seidler *et al.* (2001). *Scale Interpretation*: "Yes", 2 pts; "Partial", 1 pt; "No", 0 pt; "Unable to Determine", 0 pt.

3.3. *Meta-analysis results*

Two meta-analyses were conducted, one for exposure differences and one for differences in health outcomes. The results of the meta-analysis for exposure data are summarized in table 3 for the fixed-effect and random-effect models. The exposure limit calculations are detailed in table 3 and are based on the studies by Kumar (1990), Norman *et al.* (1998) and Seidler *et al.* (2001). The study by Stuebbe *et al.* (2002) was not included because it did not include appropriate data required for meta-analysis purposes. When study quality was not taken into consideration, the summary mean difference values (between study and control groups) were 3791 and 3942 kN s, for the fixed-effect and random-effects models, respectively, and were significantly different from 0 at the 5% level (based on confidence interval which does not include'0'). In addition, heterogeneity was significant at the 10% level ($Q = 146.66$ from table 3; Critical value for χ^2 distribution = 5.992 with 2° of freedom).

Table 3 clearly show that, by integrating the overall study quality index into the calculations, the heterogeneity among the studies becomes smaller, but still significant at 10% ($Q = 113.74$ from table 3). Additionally, by considering the overall study quality, the summary mean difference becomes larger (significant at the 5% level) (4341 kN s for the fixed-effect model and 4621 kN s for the random-effect model). Because of the significant heterogeneity among the studies, the random-effects model statistics are adopted in this paper.

Table 4 shows the results of the meta-analysis (meta-odds ratio) for the health outcome (LBD) with and without considering the quality scores for the fixed-effect and random-effects models. The meta-analysis results were only based on the data by Norman *et al.* (1998) and Seidler *et al.* (2001) because these are the only papers that included the data needed for calculation purposes. The studies by Kumar (1990) and Stuebbe *et al.* (2002) were excluded because they did not provide essential data for the meta-odds ratio calculations. Also, the odds ratio and its confidence limits for the Seidler data was recalculated in a way similar to that for Norman *et al.* (1998). The details are documented in table 4.

Table 3. Part 1 of meta-analysis: exposure data.

Source	Cases			Controls			Difference						
	n	*M*	SD	*n*	*M*	SD	*M*	SE	Weight (w1)	Heterogeneity	Overall quality index	Weight (w2)	Heterogeneity
Fixed-effect model													
Seidler *et al.* (2001)	225	28 957	11 044	187	16 118	11 044	12 839	1093	837	137.97	0.79	661	108.96
Kumar (1990)	95	14 500	12 100	52	9 300	7 700	5 200	1637	373	0.74	0.33	123	0.24
Norman *et al.* (1998)	104	21 000	4 720	130	19 500	3 840	1 500	572	3536	7.96	0.57	2016	4.53
Q										146.66			113.74
Summary mean									3791				4341
95% CI—upper									4690				5512
95% CI—lower									2891				3169
Random-effect model (Dersimonian and Laird method)													
Seidler *et al.* (2001)	225	28 957	11 044	187	16 118	11 044	12 839	1093	837		0.79	661	
Kumar (1990)	95	14 500	12 100	52	9 300	7 700	5 200	1637	13		0.33	43	
Norman *et al.* (1998)	104	21 000	4 720	130	19 500	3 840	1 500	572	3056		0.57	1742	
Summary mean									3942				4621
95% CI—upper									4934				5884
95% CI—lower									2950				3358

Note: Each weight is multiplied by E-9. The exposure measure is integrated compression over work shift and measured in kN s. The data were extracted from the original references as follows (table 3, Seidler *et al.* (2001); table 3, Kumar (1990) (female data only); table 2, Norman *et al.* (1998)). The mean was calculated as a weighted average and the standard deviation as the range divided by 4. Control group: $M = 16\,118 = (0 * 56 + 3278 * 39 + 18\,000 * 45 + 44\,175 * 47)/187$. Case group: $M = 28\,957 = (0 * 18 + 3278 * 31 + 18\,000 * 52 + 44\,175 * 124)/225$. $SD = (44\,175\ 0)/4 = 11\ 044$. It is assumed that the number of working years and days per year are 5 years and 220 days, respectively. The mid-point of each category of exposure was selected for analysis purposes. The estimate for the highest category was obtained by multiplying the lower boundary (with no upper limit) by 50%.

Table 4. Part 2 of meta-analysis: outcome data.

Source	Odds ratio	95% CL lower	95% CL upper	Without quality: Variance	Without quality: Weight (w1)	Without quality: Heterogeneity	With quality: Overall quality index	With quality: Weight (w2)	With quality: Heterogeneity
Fixed-effect model									
Seidler *et al.* (2001)	1.68	1.49	1.9	0.0037	266.70	2.52	0.79	210.69	0.03
Norman *et al.* (1998)	1.5	1.1	2	0.0250	39.94	0.39	0.57	22.76	0.24
Q						0.39			0.27
						−0.008 81			
Without quality	Summary OR		1.66						
	95% CI—upper		1.85						
	95% CI—lower		1.48						
With quality	Summary OR		1.66						
	95% CI—upper		1.89						
	95% CI—lower		1.46						
Random-effect model (Dersimonian and Laird method)									
Seidler *et al.* (2001)	1.68	1.49	1.9	0.0037	32.06		0.79	25.33	
Norman *et al.* (1998)	1.5	1.1	2	0.0250	19.05		0.57	10.86	
Without quality	Summary OR		1.61						
	95% CI—upper		2.12						
	95% CI—lower		1.22						
With quality	Summary OR		1.62						
	95% CI—upper		2.25						
	95% CI—lower		1.17						

Note: Variance refers to the variance of the estimated log odds. The data for Norman *et al.* (1998) were extracted from table 5. The odds ratio and confidence limits reported for Seidler *et al.* (2001) were recalculated in a similar way to the procedure reported by Norman *et al.* (1998) in order to provide comparable results. The data documented in table 3 in Seidler *et al.* (2001) was used for this purpose. According to Norman *et al.* (1998), a conservative estimate of risk was computed by employing the inter-quartile spread as the unit difference (i.e. the difference between the 25th and 75th percentiles of exposure levels seen in the data from the control group). Therefore, the odds ratio for the Seidler data was computed as follows: (1) the log odds were calculated for each of the exposure categories in table 3 of Seidler *et al.* (2001); (2) a regression equation was derived relating the log odds as an outcome variable and the exposure values corresponding to the 0, 25th, 50th and 75th percentiles, with no intercept; (3) point estimate was calculated as $\exp(4 * 0.13) = 1.68$, where 0.13 is the slope of regression equation with no intercept; (4) the 95% CI limits were calculated as: $\exp(4(0.13 + 1.96 * 0.015))$, where 0.015 is the standard error of the regression slope.

Because heterogeneity between the studies was not significant, only the fixed-effect model results will be considered for the outcome data (see table 4). The summary odds ratio with and without the inclusion of the overall study quality score is almost the same (meta-odds ratio 1.66). The confidence limits are slightly wider with the inclusion of the quality scores.

4. Discussion

There are a limited number of epidemiological studies which examined the association between cumulative spinal loading and lower back outcomes. Since the studies are based on cross-sectional and case-control designs, causality cannot be inferred. The epidemiological quality of these studies ranged from marginal to poor.

The summary mean difference for exposure data between the study and control groups for the published studies was significantly different from 0, regardless of whether the quality of the study was considered. The summary mean difference between the study and control groups were larger, however, when accounting for study quality. These results indicate that, from an epidemiological standpoint, the inclusion of the quality score has shifted the weighting of studies towards the higher quality studies. In addition, the summary mean difference clearly suggest that the cumulative exposure of the study groups in the published studies is much higher than that of the control groups. These study groups were mostly engaged in handling of heavy objects.

Heterogeneity testing was significant for the exposure data demonstrating that there are considerable differences among the studies in terms of methods and procedures. Of particular interest are the exposure assessment methods of cumulative spinal loading between the studies. A closer examination of the cumulative spinal loading estimation methods suggests that different techniques were employed in these investigations. Kumar (1990) used a recall interview of static postures that people were exposed to and then interpolated postures between these recalled positions to produce samples at 0.2 s intervals (5 Hz). A static model was then run on these generated postures to yield a frame-by-frame compression and shear value which was then integrated. Norman *et al.* (1998) used motion analysis to derive the peak static spinal load and multiplied these values by the number of repeats and duration of each task to yield a shift exposure.

Seidler *et al.* (2001) employed an innovative approach to data collection, using a structured interview to describe posture and load. To calculate the cumulative dose, the Jäger model was used; however, Seidler *et al.* (2001) did not exclude data for force calculations below 3.2 kN, as was suggested in the originally proposed version by Jäger *et al.* (2000). Stuebbe *et al.* (2002) used a work sampling approach (every 10 s) to calculate the cumulative load for an 8-h work shift. In this approach, the compression force was calculated for each sample, then a summation of the forces across all samples within the 8-h day was calculated.

Although exposure assessment is usually a challenging and daunting task in the occupational environment, the reliability and validity of cumulative spinal loading techniques have not been reported by most studies. At best, it has been dealt with in only one of the four studies (Seidler *et al.* 2001). Other issues such as observer and subject blinding were not addressed. Reliability, validity and usability issues associated with cumulative load methods will be examined in greater detail in a subsequent paper (Waters *et al.* 2005).

The meta-odds ratio suggests that there is an association between lower back disorders and cumulative spinal loading (meta-odds ratio = 1.66 for the fixed-effect model). These results are consistent between the studies due to the non-significant heterogeneity. The summary odds ratio is considered a crude estimate without accounting for potential confounders.

It should be noted that the results of meta-analysis for exposure and outcome data may be limited by some of the assumptions made for computation purposes. For example, with respect to the exposure data, the Kumar (1990) study has a very large standard deviation relative to the mean, indicating a non-normal exposure variable (most likely log-normal). However, the analyses in table 3 are based on normally distributed exposures. Also, the mean of the Seidler data was calculated as a weighted average and the standard deviation was obtained as the range divided by 4. Despite these assumptions, the mean difference for the exposure data was significant for each of the three studies at the 5% level. Although the odds ratios in the Seidler study were reported by different categories of exposure, the odds ratio had to be recalculated in a way comparable with the Norman calculations by employing the inter-quartile spread as the unit difference (i.e. difference between the 25th and 75th percentiles of exposure levels seen in the data from the control group). The odds ratios for the Seidler and Norman data were comparable (i.e. 1.68 in the Seidler study and 1.50 in the Norman study) and both were significant at the 5% level. These findings indicate that the assumptions made did not greatly outweigh the benefits obtained by getting a more precise estimate on a larger sample of subjects.

5. Concluding remarks

There is a critical need for cohort observational studies investigating the link between cumulative spinal loading and lower back disorders in longitudinal designs. In this regard, the methodological quality of such studies should adhere to epidemiological principles. Significant attention to detail should be paid to the quality of employed exposure assessment methods including the reliability and validity of methods for estimating force distributions and practicality for field measurement purposes. A subsequent paper examines methodological issues related to the calculation of cumulative load for epidemiological research (Waters *et al.* 2005).

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