

Chapter 8

Cumulative mechanical low-back load at work is a determinant of low-back pain.

P. Coenen
I. Kingma
C.R. Boot
P.M. Bongers
J.H. van Dieën

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ABSTRACT

Reported associations of physical exposures during work (e.g. lifting, trunk flexion or rotation) and low-back pain (LBP) are rather inconsistent. Mechanical back loads (e.g., moments on the low-back) as a result of exposure to abovementioned risk factors has been suggested to be important as such loads provide a more direct relationship with tissue failure and thus LBP. Since information on the effect of such load metrics with LBP is lacking yet, we aimed to assess this effect in a prospective study.

Of 1131 workers, categorized in 19 task groups, LBP was prospectively assessed over three years. Video and hand force recordings of four to five workers per task group (93 in total) were used to estimate mechanical low-back loads (peak load and three cumulative load metrics, i.e., linear weighted load, squared weighted load and load weighted to the 10th power) during manual materials handling (MMH) tasks using a video analysis method. These data were combined with static mechanical load estimates based on structured observation of non-MMH tasks. Associations of mechanical loads and LBP were tested using generalized estimating equations.

Significant effects on LBP were found for cumulative low-back moments (linear and squared weighted; both $p < 0.01$ and odds ratios of 3.01 and 3.50 respectively) but not for peak and cumulative moments weighted to the tenth power.

Results of this first prospective study on the effect of mechanical low-back load on LBP support a LBP etiology model of cumulative loads, potentially due to accumulation of micro-damage or fatigue.

INTRODUCTION

Epidemiological studies have contributed to our understanding of the etiology of low-back pain (LBP). According to these studies, LBP is associated with personal risk factors (e.g. age, smoking habits, physical capacity and body weight (Hamberg-van Reenen et al., 2007)), psychosocial risk factors (e.g. stress, social support and job satisfaction (Hartvigsen et al., 2004)), and physical risk factors. Of these physical risk factors, twisting, bending, lifting and whole body vibrations are most frequently reported (Griffith et al., 2012; Lötters et al., 2003). However, it has also been argued that evidence concerning these physical risk factors of LBP is weak, possibly as a result of the use of measurement tools with low accuracy (Bakker et al., 2009). Specifically, measuring physical risk factors for LBP often relies on self-reports or observations that, although proven to be valid and reliable, can have weak associations with LBP (Griffith et al., 2012). Moreover, objective field-based measurements often lack a clear description of all dimensions of the exposure to the risk factors i.e. duration, frequency and magnitude (Takala et al., 2010). It can be argued that mechanical low-back load metrics (e.g., spinal compression forces or moments at the low-back) provide more information than low-back exposure measures (e.g., the number of lifts or time spend in a flexed trunk position). One reason for this is that exposure metrics do not always have consistent relations with load metrics. For example, the mass lifted is a poor predictor of low-back moments (Hoozemans et al., 2001). Furthermore, different exposures affect the same mechanical load. Therefore, load metrics can be expected to be more strongly associated with LBP for which some empirical support has already been provided (Coenen et al., 2013b; Norman et al., 1998).

Several models for the causal chain of LBP etiology have been proposed, all assuming that tissue failure due to mechanical load on the back, as a result of abovementioned variables, is a cause of LBP (Chaffin, 2009; Marras, 2012). In general, two pathways for the occurrence of tissue failure can be considered: LBP may result from instantaneous tissue failure due to peak loads on the low-back, or from cumulative loads. Cumulative loads could cause LBP, for instance through accumulation of micro-damage, or through impaired coordination due to respiratory (Brereton & McGill, 1999; Janssens et al., 2010) or neuromuscular (Sparto et al., 1997; van Dieën et al., 1998) fatigue. The predictive value of a variety of parameters of low-back loading for the risk of LBP has been assessed, showing that both cumulative (Coenen et al., 2013b; Kumar, 1990; Norman et al., 1998) and peak spinal loads (Neumann et al., 2001; Norman et al., 1998) are associated with the LBP prevalence. These findings militate in favor of both of the two abovementioned causal models. However, results are based on retrospective studies or on prospective studies using exposure risk factors rather than low-back load metrics. Such studies can be of paramount importance to gain more insight into the etiology of LBP.

Although there is currently no gold standard for obtaining mechanical low-back load metrics from workers in a field setting (Takala et al., 2010), video based coding methods

(Xu et al., 2011) that assess postural data, which are subsequently used in biomechanical models estimating mechanical low-back load (Coenen et al., 2011; Sutherland et al., 2008), are suitable for this purpose. These methods allow for obtaining accurate mechanical low-back load estimates in field settings without interfering with the worker's tasks. The video-based method that is used in the current study has been validated against a lab-based gold standard (Coenen et al., 2011) and inter-rater reliability of this method has been assessed in the field, showing inaccuracies of approximately 10% of maximum loads (Coenen et al., 2013a). The objective of the present study was to assess the effect of peak and cumulative low-back load metrics on LBP in a prospective cohort study using this video analysis method. To the best of our knowledge, there are currently no data available from prospective studies assessing mechanical low-back load in work site situations. Moreover, it is not yet clear how, in calculating cumulative loads, repetition of loading should be weighted relative to load intensity. As suggested before (Brinckmann et al., 1988; Rapillard et al., 2006), it is likely that the magnitude of peak loads has more impact on the risk of failure than the number of times a load occurs. Therefore, several weightings of these peak loads in the calculation of cumulative loads have been proposed, including raising the loads to a certain power, e.g., squared (Coenen et al., 2012; Seidler et al., 2009), fourth order (Jäger et al., 2000) and even tenth order weighting (Coenen et al., 2012). A higher order weighting reflects a higher importance of load intensity compared to the number of loading cycles. In the current study, the effect of several weightings for cumulative loading will be tested, i.e., linear weighting, squared weighting and tenth order weighting, where the latter two are expected to have a higher predictive value for LBP.

METHODS

Population and data collection

Data used in this study were collected as part of the Study on Musculoskeletal disorders, Absenteeism and Health (SMASH) that aimed to assess risk factors of musculoskeletal disorders among Dutch workers (Ariëns et al., 2001; Hoogendoorn et al., 2000). Briefly, workers from various industrial and service branches, for example, the metal, chemical, pharmaceutical, food and wood construction industry; waste processing, insurance and distribution companies were studied. The study consisted of a baseline measurement, assessing low-back load at the workplace and potential confounders, and a baseline and three year follow-up assessment of musculoskeletal symptoms. Ethical approval for this study was obtained from the *Netherlands* Organization for Applied Scientific Research (TNO) ethics committee. Any identifiable subjects have provided their signed consent to publication and participants gave informed consent before taking part in the study.

Personal factors such as age and gender were assessed using self-administered questionnaires. Furthermore, a Dutch version of the Karasek's Job Content Questionnaire for psychosocial work characteristics was used to assess job demands, decision authority,

co-worker support and supervisor support (Karasek, 1985). Exercise behavior during leisure time was assessed with the Leisure Time Exercise Questionnaire (Godin et al., 1986). Driving a vehicle during work and during leisure time, and physical exposure during leisure time were assessed with the Loquest questionnaire (Hildebrandt & Douwes, 1991). The occurrence of LBP was assessed using a Dutch version of the Nordic Questionnaire (Kuorinka et al., 1987). LBP at baseline and during the three consecutive years of follow-up was defined when subjects reported regular or prolonged LBP in the 12 months prior to filling out one of the questionnaires.

At baseline, 1990 of the 2048 workers who were invited for the study participated and 1802 (91%) of these workers completed the baseline questionnaires. Of these workers, LBP data in at least one of the years of follow-up were available for 1131 workers. All these workers filled in the LBP questionnaires at baseline and during the first year of the follow-up, while 1004 and 994 workers filled in the LBP questionnaires during the second and third year of the follow-up respectively. These workers were classified into 19 task groups, based on physical exposure. For 371 workers, approximately 25% of all workers within each task group, 5-15 minutes of video recordings at the workplace were taken at four randomly chosen moments during the course of one day. Furthermore, external forces at the hands during these periods were measured using force transducers (during pushing and pulling) or weighting scales measuring mass of the external load (for lifting tasks). Videos were observed during which manual material handling tasks (MMH tasks; i.e. lifting, pushing and pulling tasks) were identified, yielding a total of 12,924 tasks. In the current study, only task groups with at least four observed workers were included. From each task group, four or if available five workers were analyzed to assess mechanical low-back load. As a result, 4872 MMH tasks of a total of 93 workers were selected for the current study (Table 8.1). On average there were 58 ± 103 MMH tasks per worker, ranging from 0 to 534 tasks. Video recordings of the 4872 MMH tasks were used for the assessment of mechanical low-back load using video analysis as described in the next paragraph.

Table 8.1 | Descriptive statistics of the entire cohort (first column), the group of workers from whom video recordings were available (second column) and the group of workers mechanical loads were calculated from in the current study (third column). Number of subjects, age, gender, LBP during in one of the four questionnaires, number of MMH tasks

	Total	Recorded	Analyzed
Number of workers (n)	1131	371	93
Age (years)	36 (9)	36 (9)	36 (9)
Males (n(%))	800 (71%)	216 (68%)	61 (66%)
LBP (n(%))	600 (53%)	199 (54%)	48 (52%)

Assessment of mechanical low-back load

Ten raters were recruited among students of the Amsterdam School of Health Professions and the Faculty of Human Movement Sciences of the VU University, Amsterdam. After participating in an extensive learning and practice session in which they were familiarized with the software, each rater analyzed videos of a selection of tasks. Raters analyzed videos independently from each other and were asked to rate as many tasks as possible, including tasks that were not recorded optimally (e.g., due to partial occlusion of the view or when the task was not recorded from a sagittal plane view). Furthermore, raters were blinded from the fact whether they rated a worker that either had or had not reported LBP.

Videos of all 4872 MMH tasks were rated, using an earlier developed video-analysis method that has been described extensively before, and was tested on validity and inter-observer reliability (Coenen et al., 2011; Coenen et al., 2013a; Xu et al., 2011). Begin and end frames of the tasks were selected from the video and two intermediate frames were automatically selected to obtain four video frames. On each video frame, a manikin was fitted consisting of nine segments (right foot, lower leg and upper leg; pelvis, trunk/head, two upper arms, two forearms/hands). This manikin allows for semi three-dimensional analysis of movements (ankle flexion/extension, knee flexion/extension, hip flexion/extension, trunk flexion/extension, trunk rotation, trunk lateral flexion, shoulder flexion/extension, shoulder abduction and elbow flexion/extension). Furthermore, the manikin can be scaled, rotated around its longitudinal axis (axial rotation) and translated horizontally and vertically along the video frame, which allows the rater to make an optimal fit of the manikin to the video frame. Subsequently, interpolations of the segment angles over the four key frames were executed to estimate workers' body kinematics (Xu et al., 2010). Based on total body mass and stature, individual segment masses and lengths, positions of the center of mass and inertia tensors were estimated (Zatsiorsky, 2002). A top-down 3D inverse dynamics calculation using hand forces, segment kinematics (obtained from the interpolated manikin postures) and anthropometrics was performed to assess resultant moments at the level of the L5/S1 joint. For each MMH task, peak moments were calculated. Workers that did not perform any MMH tasks during the collection of video were assigned a peak load as obtained from an earlier calculation of mechanical low-back load (Coenen et al., 2013b). In this latter study, moments were calculated based on static postures while these postures were based on continuous structured visual observation of all video material of each worker. In these observations, postures were categorized into four categories of trunk flexion, two categories of trunk rotation and four categories of arm elevation.

For cumulative load, a time series for the complete video recordings of the 93 subjects was constructed in which the abovementioned estimation of low-back moments based on observations for non MMH tasks was added to moment time series of all analyzed MMH tasks of the subject. Cumulative moments were then estimated by calculating the

area under the moment curve while outcomes were extrapolated to an entire work week (based on the length of the observation and the working hours per week). Peak load was defined as the maximum peak in the complete time series. Three kinds of cumulative moments were calculated: area under the curve, area under the squared curve and area under the curve to the 10th power. Of the four variables (one peak load variable and three cumulative loads), group-based loads (in which average group load estimates are assigned to all members within each task group) were calculated and were used as potential risk factors for LBP in further statistical analyses. To facilitate the interpretation of the ORs presented in the current study, the metrics were divided by 1·10², 1·10⁵, 1·10⁷, 1·10¹⁰ for peak moments, non-weighted cumulative moments, squared weighted cumulative moments and moments weighted to the tenth power respectively. Calculations were performed using custom developed Matlab software (version 7.7.0).

Statistical analyses

All analyses were executed for the four load metrics separately. The crude effect of the mechanical low-back loads on LBP were assessed using univariate Generalized Estimating Equations (GEE) with the load (as continuous variables) being the independent variable and LBP (dichotomous outcome of the four measurements –baseline and three years of follow-up-) being the dependent variable. Furthermore, the contribution of a number of potential confounders was explored with multivariate GEE using a forward stepwise selection procedure with the load being the independent variable and LBP being the dependent variable, as described above. Only confounders that led to a change of >10% in the beta depicting the effect of the mechanical load on LBP were included in the model (Twisk, 2006). The following potential confounders were considered, based on previous studies (Coenen et al., 2013b; Hoogendoorn et al., 2000): age, gender, smoking habits, body mass index, physical activity in leisure time, quantitative job demands, decision authority, skill discretion, supervisor support, co-worker support, work security, driving a vehicle during work and leisure time, sitting at work, flexion/rotation of the trunk during leisure time, moving heavy loads during leisure time. In the final four models, the effects of the potential risk factors adjusted for all potential confounders were assessed using multivariate GEE. In all GEE analyses an exchangeable correlation matrix was used. Only for univariate models, quasi likelihood under the independence model criterion (QIC) were calculated depicting the goodness of fit of the models; a lower QIC values was interpreted as a better fit (Pan, 2001). Odds ratios (ORs) and 95% confidence intervals, and corresponding p-levels were estimated for the mechanical low-back loads. P-values <0.05 were considered statistically significant.

To test the robustness of the current selection of 5 workers per task group, we combined our data with 2,339 MMH tasks (74 workers) that had been additionally analyzed (but were not uniformly distributed over the 19 task groups) for other purposes, and we

performed 25 random drawings of 5 workers per task group. For each drawing, the effect of the four mechanical load measures on LBP was assessed univariately as described above; p-values of these effects were calculated. All statistical analyses were performed using SPSS (version 20).

RESULTS

Out of all identified MMH tasks, 4,168 (86%) tasks were analyzed. The remaining selected tasks could not be analyzed due to unsatisfactory low quality of the video material (e.g., partial occlusion of the view). On average 52 (90) tasks per subject were analyzed, with an average external force measured at the hands of 72 (60)N. Of these tasks, 3,566 (86%) were lifting tasks, 450 (11%) were pushing tasks and 152 (3%) were pulling tasks.

Linear and squared weighted cumulative load had a significant on LBP, univariately (both $p < 0.01$), as well as when adjusted for confounders (both $p < 0.01$; Table 8.2). Cumulative loads weighted to the tenth power and peak moments did not have a significant effect on LBP, neither when effects were calculated univariately ($p = 0.70$ and $p = 0.12$ respectively), nor when adjusted for confounders ($p = 0.74$ and $p = 0.73$ respectively). Regarding the goodness of fit, a comparable pattern could be found, since linear and squared weighted cumulative loads led to better fits compared to cumulative loads weighted to the tenth power and peak moments. Furthermore, squared cumulative loads led to a slightly better fit than linear weighted cumulative loads. In order to facilitate interpretation of these data, ORs adjusted for confounders for linear and squared weighted cumulative loads (model 3 in Table 8.2) were used to calculate ORs corresponding with a difference in mechanical load of the task groups with the highest mechanical load compared to the group with the lowest mechanical load. This calculation provided ORs of 3.01 and 3.50 for the two metrics respectively.

The robustness analysis of the four mechanical load metrics showed that the estimate of the linear and squared weighting of cumulative loads were robust as comparable p-levels (all < 0.01) were shown for all drawings (Figure 8.1). The effect of peak loads was moderately robust leading to univariate significant effects ($p < 0.05$) in six out of the 25 drawings. However, the tenth power weighting of cumulative load was not robust, with a significant effect in one out of the 25 drawings and p-values ranging from < 0.01 to 0.87.

Table 8.2 | Effects of mechanical low-back loads on LBP presented the four mechanical low-back load risk factors. For each risk factor, three models are presented: A crude model (Model 1), a model corrected for statistically significant confounders (Model 2) and a model corrected for all potential confounders (Model 3). For univariate models, QIC scores are shown.

Moment	Expressed	LBP		No LBP		Model1		Model2		Model3		
		Mean (St. Dev.)	Mean (St. Dev.)	Mean (St. Dev.)	Mean (St. Dev.)	OR (95% CI)	p	QIC	OR (95% CI)	p	OR (95% CI)	p
Peak	/10 ²	1.45(0.61)	1.38(0.57)	1.38(0.57)	1.38(0.57)	1.14(0.97-1.35)	0.12	5219.15	1.05(0.81-1.37)	0.69	1.05(0.81-1.36)	0.73
Cumulative	/10 ⁵	23.3(12.5)	21.4(6.7)	21.4(6.7)	21.4(6.7)	2.12(1.41-3.16)	<0.01	5197.78	2.01(1.22-3.31)	0.01	2.15 (1.29-3.58)	<0.01
Cumulative ¹⁰	/10 ⁷	12.2(12.7)	10.1(6.2)	10.1(6.2)	10.1(6.2)	2.16(1.47-3.17)	<0.01	5194.34	2.12(1.39-3.22)	<0.01	2.19(1.35-3.56)	<0.01
Cumulative ¹⁰	/10 ¹⁰	7.61(28.61)	6.60(27.64)	6.60(27.64)	6.60(27.64)	1.21(0.90-1.17)	0.70	5221.55	1.02(0.88-1.18)	0.77	1.03(0.89-1.18)	0.74

Expressed = Defines the units in which the ORs are expressed.

OR (95% CI) = Odds ratio and 95% confidence interval depicting the effect of the mechanical load on LBP

p = level of significance depicting the effect of the mechanical load on LBP

QIC = Quasi likelihood under independence model criterion, depicting the goodness of fit of the univariate mechanical loads.

Model1: Univariate model

Model2: Model adjusted for the following statistically significant confounders:

Peak: Gender, quantitative job demands, work security, physical activity in leisure time, smoking habits, driving a vehicle during work, rotation of the trunk during leisure time, co-worker support, decision authority, supervisor support, moving heavy loads during leisure time, driving a vehicle during leisure time, sitting at work

Cumulative: Gender, co-worker support, driving a vehicle during leisure time, sitting at work

Cumulative2: Gender, smoking habits

Cumulative10: Gender, smoking habits, physical activity in leisure time, quantitative job demands, skill discretion, supervisor support, co-worker support, driving a vehicle during leisure time, sitting at work

Model3: Model adjusted for all potential confounders

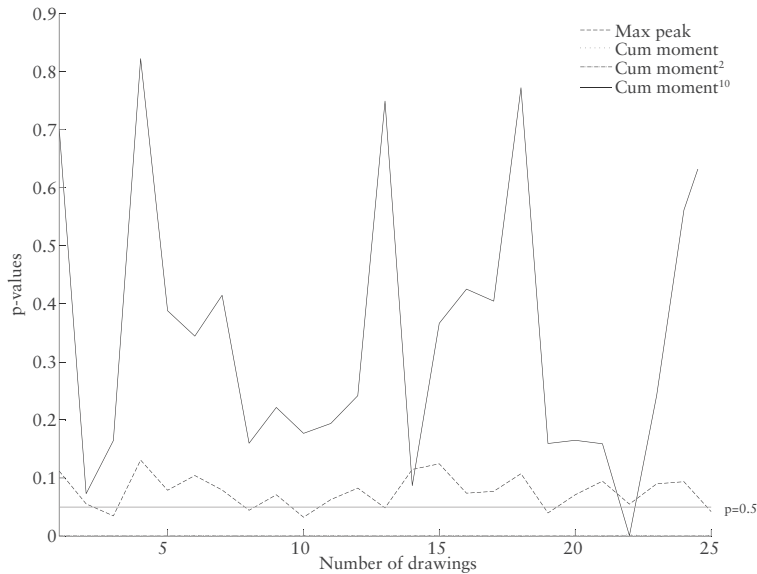


Figure 8.1 | Univariate effect of the four mechanical low-back loads on LBP during 25 random drawings of 5 subjects per task group. Note that all drawings for linear and squared weighted loads have rather small values (all < 0.01). A level of significance $p=0.05$ is presented with the grey line.

DISCUSSION

The aim of the present study was to assess the effect of mechanical low-back load metrics on LBP in a prospective cohort study. It can be concluded that cumulative loads are strong predictors of LBP. These findings are in line with the model of LBP etiology due to accumulation of micro-damage and with previous studies showing associations of cumulative mechanical back loads with LBP (Coenen et al., 2013b; Kumar, 1990; Neumann et al., 2001; Norman et al., 1998). Despite the fact that we showed previously that in-vitro failure of spine segments during repeated loading at a constant load levels is best predicted when using a tenth power of load level (Coenen et al., 2012), this metric did not have a significant effect on LBP in our data. The higher the order of the weighting, the larger the contribution of load magnitude to the risk estimate compared to frequency of loading. The latter study was based on a mechanical load protocol applied on in-vitro material. On the one hand, in-vitro material lacks the potential to repair micro-damage, which would cause an overestimation of the importance of the loading frequency. On the

other hand, in-vitro testing does not take into account that the risk of low-back injury may increase when respiratory or neuromuscular fatigue causes impaired coordination (Brereton & McGill, 1999; Janssens et al., 2010; Sparto et al., 1997; van Dieën et al., 1998). This leads to an underestimation of the importance of the temporal characteristics of loading. As we show here that squared weighting load has, but load weighting to the tenth power does not have an effect on LBP, the latter characteristic of in-vivo conditions may play an important role here. However, this reasoning may be premature, since the lack of predictive value of the tenth power weighting might also be a result of the fact that the metric is highly affected by inaccuracies in the measurements or actual variation in the work pattern. This can also be deduced from the non-robust nature of the effect of this metric on LBP (Figure 8.1).

As has been suggested before, it is likely that the magnitude of peak loads has more impact on the risk of failure than the number of times a load occurs (Brinckmann et al., 1988; Rapillard et al., 2006). This led us to predict that, in the calculation of cumulative loads, weighted peak loads would be more predictive of LBP than non-weighted peaks. Because squared cumulative loads tended to have a slightly better fit than linear weighted cumulative load, the use of such weighting is recommended for future studies. It should be kept in mind that the design of the present study, with group-based averaging of load metrics and a long follow-up period for the assessment of LBP does not allow any inference on the importance of occasional peak loads leading to acute injury and pain. In the present study, peak moments did not have an effect on LBP. Although, this lacking effect was moderately robust leading to significant effects in some cases of the repeated drawings univariately, effects were highly non-significant when adjusted for confounders. Therefore, our findings provide stronger support for the cumulative load induced tissue failure model than for the peak load induced tissue failure model. A difference in mechanical load corresponding with a difference of the task groups with the highest mechanical load compared to the group with the lowest mechanical load can be interpreted with ORs of 3.01 and 3.50 for linear and squared cumulative loading respectively. These values suggest substantial risks of LBP in the group of workers with the highest mechanical loads (mainly road workers with high external forces). Prevention of LBP should therefore be targeted on such tasks. Moreover, these ORs are higher than pooled ORs reported in earlier studies for exposures metrics (Griffith et al., 2012). Therefore, the present results are in line with earlier studies suggesting higher associations for mechanical loads as compared to exposure metrics (Coenen et al., 2013b; Norman et al., 1998).

The strength of the present study is that the results are based on a large prospective cohort study and that, for the MMH tasks, low-back loading was assessed more accurately than in epidemiologic studies performed thus far. Furthermore, the current study is based on an assessment of mechanical load that has been proven to be valid (Coenen et al., 2011) as well as reliable among raters in field settings (Coenen et al., 2013a). However,

the video analysis method contains some limitations. Only MMH tasks were assessed with the current method, while moments during the remaining part of the video recording were estimated, based on static postures obtained from postural observation categories (Coenen et al., 2013b). This was performed under the assumption that the highest mechanical loads derive from MMH tasks. However, from the current data, it cannot be ruled out that a source of bias is introduced due to this procedure. Therefore, when future techniques allow for continuous measurement of mechanical loads, improvements in the predictive value of mechanical loads can be expected. Furthermore, the video analysis used may yield occasional large errors, e.g., due to inherent inaccuracies in manikin fitting (that are amplified in tasks of very short duration). These inaccuracies can originate from occlusion of the view or in highly non-sagittal plane recordings. However, these errors were shown to have a random character (Coenen et al., 2011; Coenen et al., 2013a). Furthermore, as multiple MMH tasks per subject were assessed and as group-based values were calculated in a pool of workers, these random errors are likely to be diminished. However, as has been indicated above, such errors are amplified when using higher order weighting in cumulative load calculations.

In this study, only a limited number of workers were assessed. Mechanical load data were assessed for four or five subjects per task group, introducing the possibility of selection bias, as the rest of the 371 workers, from whom observational data were available, were not analyzed. Such group-based approaches have been adopted before (Ariëns et al., 2001; Hoogendoorn et al., 2000) and have proven to be successful for the assessment of work load in several occupational tasks. Such group-based estimates of work load have been shown to be more reliable than individual estimates (Hoozemans et al., 2001; Paquet et al., 2005), leading to higher predictive values (Jansen & Burdorf, 2003), as individual random errors are reduced. These studies furthermore illustrate that, with an increase in the number of workers sampled, the work load estimate improves less when continuing to add more subjects, which suggests that measuring too many subjects when calculating group-based work load is inefficient. In a simulation study, it was furthermore shown that a total of five workers per task group should be sufficient to obtain significant risk associations for LBP (unpublished data). Furthermore, from the data presented in Figure 8.1, it can be concluded that, at least for the two significantly predictive cumulative load metrics, ORs and p-values comparable to the ones we have reported, are found when varying the selection of workers for low-back load assessment. The current selection of workers is therefore likely to be representative. Moreover, the selection of workers for whom low-back load was measured was highly comparable to the entire group of workers with respect to age, gender and prevalence of LBP (Table 8.1). Therefore, selection bias is not likely to have had a strong impact in the present study. A final source of bias might have emerged from the fact that workers were video-taped at four randomly chosen occasions of the work day for a finite amount of time rather than during the whole work

day. Distributing these four occasions over several days might have resulted in a more precise work load estimates, as work load will most likely vary more between days than within days (Mathiassen et al., 2003; Paquet et al., 2005). This issue was addressed by measuring several workers at different days in each task group, to obtain more precise estimates of the work load within groups (Mathiassen et al., 2003; Paquet et al., 2005). The appropriateness of our measurement strategy was furthermore supported by showing small within group variability of observation-based exposure estimates in a previous study on the same population (Ariëns et al., 2001).

From this first prospective study on the effect of mechanical low-back load on LBP, it can be concluded that cumulative low-back loads are predictive for the occurrence of LBP. However, a significant effect was not found for peak loads. Therefore, these findings provide stronger support for a model of LBP etiology due to cumulative loads than for a model based on single peak loads. Information obtained from this study can teach us on the biomechanical etiology of LBP. Such information can be of vital importance for policymakers and ergonomic practitioners when designing LBP prevention programs. Based on the current results, such programs should focus on reducing cumulative low-back loads.