Effects of measurement strategy and statistical analysis on dose-response relations between physical workload and low back pain

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ORIGINAL ARTICLE

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Background: In epidemiological studies on physical workloads and back complaints, among the important features in modelling dose-response relations are the measurement strategy of the exposure and the nature of the dose-response relation that is assumed.

Aim: To evaluate the effect of these two features on the strength of the dose-response relation between physical load and severe low back pain.

Methods: The study population consisted of 769 workers in nursing homes and homes for the elderly. Observations at the workplace were made of 212 subjects. These observations were analysed to determine exposure to physical load according to two measurement strategies: the individual approach and the group approach. The nature of the dose-response relation was evaluated with nested logistic regression models.

Results: The group approach resulted in higher odds ratios for the associations between physical load and low back pain than the individual approach. Spline logistic regression models appeared to describe the dose-response relation between physical load and low back pain best. The corresponding curve showed small changes in risk for small changes in exposure, whereas the categorical model only showed sudden large changes in risk at predefined exposure values.

Conclusion: The choice for a particular measurement strategy of physical load influences the strength of the associations between physical load and severe low back pain. Spline models allow changes in risk over the whole exposure range and are therefore a promising approach to identify quantitative dose-response patterns between physical load and low back pain.

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Back disorders are a major health problem in many occupational populations. Among others physical load has been identified as a significant contributing factor in the occurrence of low back pain (LBP).[1 2] Despite the evidence associating LBP with these variety of work factors, quantitative dose-response relations are far from clear. In most studies assessment of physical load is based on qualitative self-reports or on an expert's opinion on presence or absence of generic risk factors such as awkward postures, static load, and heavy labour. In order to study dose-response relations between physical load and LBP, attention needs to be directed to quantitative characterisation of physical load. In the past two decades several methods have become available that facilitate a more a quantitative approach to assess physical load in the workplace, such as observation techniques. Observation techniques have the advantage of being easily applicable in many work situations combining sufficient detail of the important dimensions of physical load.[3 4]

In general, to measure exposure levels of physical load with observation techniques two approaches can be used: (1) the individual approach, in which every worker is observed; and (2) the group approach, in which subjects are grouped into several a priori defined groups and samples of these groups are observed. It has been shown that the group approach may greatly reduce the measurement effort required, but at the expense of precision of the risk estimates.[5 6] The individual approach is often associated with considerable random error and, hence will lead to the attenuation of risk estimates. This is less likely using the group approach, given that enough subjects are observed with a sufficient number of repetitions. In contrast to the group approach, the effect of measurement error on the degree of attenuation is well described for the individual approach, and several authors have suggested methods for the correction of risk estimates for measurement error.[5 7–9] To our knowledge, the choice of the measurement approach on the measures of association between exposure and outcome in musculoskeletal epidemiology has never been evaluated.

The quantitative relation between physical workload and the occurrence of LBP is not monotonic increasing, with an increased intensity or duration of exposure resulting in an increased risk of disease. When describing dose-response relations for physical load, a U-curve probably better describes the nature of the associations.[10 11] Modelling the dose-response relation between physical load and LBP with statistical models that follow a linear form may be unable to identify existing patterns of exposure and associated risks when applied over the whole exposure range. Modelling the dose-response relation by breaking the range of study exposure (physical load) in several categories and comparing the trend in category-specific risk estimates also has drawbacks. Among others, it assumes homogeneity of risk within categories of exposure and allows large changes in risk between these categories.[12] An alternative to these

Abbreviations: LBP, low back pain; SSG, dataset of subset of 212 observed workers and exposure to physical load determined by the group approach; SSI, dataset of subset of 212 observed workers and exposure to physical load determined by the individual approach; WSG, dataset of whole study population and exposure to physical load determined by the group approach

Main messages

- In order to study dose-response relations between physical load and low back pain attention needs to be directed to quantitative characterisation of physical load.
- Exposure to physical load at the workplace measured by the group approach—samples of predefined occupational groups are observed—resulted in stronger associations between physical load and low back pain than with the individual approach where every worker is observed.
- Statistical models that anticipate a linear relation between physical load and low back pain may be unable to identify patterns of exposure and associated risks when applied over the whole exposure range. Categorical models with broad categories of exposure may not reflect relevant effects of physical load on low back pain as well.
- When valid quantitative estimates of physical load are obtained, this enormous measurement effort asks for statistical techniques that make full use of the informational content. Spline models are a promising approach.

Policy implications

- When in epidemiological or ergonomic studies the objective is to estimate dose-response relations between physical load and low back pain, not only study design, sample size, and handling of bias are important, but the measurement strategy has to be considered as well.
- In dose-response studies consider statistical models that are more flexible than linear and categorical models and that are capable of reflecting relevant dose-response patterns.

approaches is spline analysis. Like categorical regression analysis the splines allow changes in risk at the boundaries of the categories. However, the advantage of the spline approach is that it also makes use of information within categories of exposure (as is not the case with the categorical analysis). Splines allow the risk to vary within and between categories of exposure.[13]

The purpose of the present study is: (1) to evaluate the effect of measurement strategy of physical workload on the relations between physical workload and LBP; and (2) to compare dose-response relations of physical workload and LBP acquired with different statistical techniques.

MATERIALS AND METHODS

Population

The subjects in the present study (n = 769) participated in a large epidemiological study among nursing home personnel. The study population consisted of nine different occupational groups: 129 nurses, 264 care givers, 58 kitchen workers, 49 housekeepers, 14 transportation and technical workers, 9 laundry workers, 38 (physical) therapists, 146 office workers, and 62 miscellaneous workers. All subjects worked for more than 10 hours a week.

Data collection

Questionnaire survey

Information on back problems during a period of 12 months was gathered with self administered questionnaires. The questions were derived from the Nordic questionnaire for the analysis of musculoskeletal symptoms.[14] Severe LBP was defined as an episode of low back problems in the past 12 months with severe pain, defined as those subjects whose back problems exceeded the pain intensity score of 50 according to the Von Korff scheme for gradation severity of chronic pain.[15] A total of 153 of the 769 subjects (19.8%) experienced an episode severe LBP in the past 12 months.

The Karasek job control, skill discretion, job demands dimensions were used to collect information on psychosocial work demands.[16] These dimensions were combined in a dichotomous measure reflecting ‘‘low job decision latitude with high job demands’’ versus ‘‘other’’.

Quantitative assessment of physical load

Among a random sample of 212 workers, observations at the workplace were performed to collect information on physical load during work among the nine a priori defined occupational groups. In this study an observational multimoment method was used to describe three measures of physical load: trunk flexion over 20°, trunk flexion over 45° and lifting or carrying loads over 10 kg, all expressed in percentage of work time. On each of the workers observations were made every 20 seconds during four periods of 30 minutes stratified over one whole working day, thus collecting 360 observations per worker.

Individual approach

For each of the 212 observed workers, the subset of the population, the individual exposure to the different physical workloads was estimated by the average percentage of work time over the four measurement periods on that subject.

Group approach

For each occupational group the average exposure to the physical workloads of that group was calculated as the average of the individual exposure of the observed workers (as determined by the individual approach) in that group. This group arithmetic mean was used as a proxy for exposure of all subjects, both observed and unobserved, in a given occupational group.

In addition to the subject's average exposure expressed in *percentage work time* a cumulative exposure to physical load per work week was calculated by multiplying the average exposure with the number of work hours per week per individual. With the individual approach this cumulative exposure is expressed in *work hours per week* for the subset of 212 workers, and with the group approach this cumulative exposure is expressed for both the subset as well as each worker in the study (n = 769).

Data analysis

Physical load

To estimate the ratio of the between subject variance of the physical workloads and the within subject variance of the physical workloads a one way analysis of variance was performed. A random effect model was used, since the observed workers were regarded as random ‘‘samples’’ from the total study population, and the four repeated measurements on each worker were assumed to be drawn at random from the total exposure distribution from each worker. Since the underlying distributions of exposure were assumed to be best described by normal distributions, the variance components were estimated by S^2_{bs} (between subject variance) and

S^2_{ws} (within subject variance), using proc NESTED in SAS statistical software.[17] To estimate the partitioning of the total variance in the variance components, occupational groups, subjects, and within subjects, a nested two way analysis of variance was performed.

Measurement approach, physical load and low back pain

To evaluate the effect of the two measurement approaches (the individual approach and the group approach) on the associations between physical load and severe LBP, logistic regression analyses were performed on three sets of data: (1) dataset WSG consisted of the whole study population and exposure to physical load was determined by the group approach; (2) dataset SSI consisted of the subset of 212 observed workers and exposure to physical load was determined by the individual approach; (3) dataset SSG consisted of the subset of 212 observed workers and exposure to physical load was determined by the group approach. Finally the estimates with the individual approach were corrected for measurement error according to Lui and colleagues.[9]

Nature of the dose-response relations of physical load and low back pain

To analyse dose-response relations for the physical load factors (expressed in work hours per week) and severe LBP, a sequence of nested logistic regression models[13] were compared using dataset WSG. The models assessing the dose-response relations were: (1) the linear logistic regression model; (2) the quadratic logistic regression model (a quadratic term for the exposure added to the linear model); (3) the quadratic spline logistic regression model; and (4) the restricted quadratic spline logistic regression model. In contrast to the linear (and quadratic) model, the spline model allows for flexibility in modelling the dose-response curve. Specifically if the exposure measure is divided into a number of intervals, then a linear spline would model the response as a series of line segments connecting these points. To smooth out the connections between the line segments a further improvement is the quadratic spline, which allows for a parabolic curve to connect the points. Because of the possibility of instability in the tails of the exposure measure, a restricted spline model allows for the curve at either end to be replaced by a line segment. Performance of the four logistic regression models in terms of goodness of fit was judged by the use of likelihood ratio statistics. The model that described the dose-response relations best was compared with the classical categorical models.

For the categorical analysis and the splines the continuous physical load variables were divided into four categories based on the distributions of these variables with cut offs at 25th, 50th, and 75th centiles of exposure. Next to the physical workloads, potential confounders psychosocial work demands and age were entered in the model as co-factors. The models were fitted on data of the whole study population (dataset WSG) and parameters were estimated with proc Logistic in SAS statistical software.[17] With proc IML available in SAS, odds ratios (OR) and 95% confidence intervals (95% CI) were calculated with reference to exposure at the midpoint of the lowest exposure category (12.5th centile of the distribution).

RESULTS

Physical load

Table 1 presents results of the analysis of variance of the observations of physical load (measured with the individual approach). The overall percentage of working time in trunk flexion over 20° was 20.4%, for trunk flexion over 45° was 4.4%, and for lifting and carrying over 10 kg, 0.9%. Considerable differences existed between workers' exposure levels (the between subject variance). Furthermore, the largest variance ratio of within and between subject variance was found for lifting and carrying loads over 10 kg. In table 2 the distribution of the variance over the groups, workers, and within workers is presented. Assigning the workers to occupational groups reduced the between subject variance, with the between group variance not capturing more than 10% of the total variance. The within subject variance captured 58.6–82.2% of the total variance.

Table 1 Overall mean and variability of trunk flexion over 20°, trunk flexion over 45°, and lifting and carrying loads over 10 kg, expressed in percentage work time

(n = 212)	Mean (SD)	S^2_{bs}	S^2_{ws}	λ
Trunk flexion over 20°	20.4 (11.4)	96.8 (41.3%)	137.0 (58.7%)	1.4
Trunk flexion over 45°	4.4 (4.5)	14.2 (35.9%)	25.5 (64.1%)	1.8
Lifting and carrying loads over 10 kg	0.9 (1.6)	1.2 (16.5%)	6.2 (83.5%)	5.2

SD, standard deviation; S^2_{bs}, between subject variance; S^2_{ws}, within subject variance; λ, variance ratio S^2_{ws}/S^2_{bs}.

Physical load and low back pain, the effect of measurement approach

Table 3 presents the effect of the measurement approach on the observed associations between physical load and severe LBP. In reference to the measurement error corrected estimates the individual approach (SSI) showed that measurement error had an effect on the point estimates for trunk flexion over 45° and lifting and carrying loads over 10 kg; the uncorrected estimates were closer to unity. The attenuation (defined as the relative difference between corrected and uncorrected estimates) of exposure to physical load expressed in percentage of work time was comparable with the attenuation of exposure expressed in work hours per week.

The group approach resulted in higher odds ratios than the individual approach at the expense of larger confidence intervals. Dataset WSG showed significant associations for the effect of trunk flexion over 45° and lifting and carrying loads over 10 kg expressed in percentage work time. These associations were not present when exposure was expressed in work hours per week.

Physical load and low back pain, nature of the dose-response relations

Figure 1 presents the traditional way to analyse the dose-response relation between lifting and carrying over 10 kg and severe LBP with the categorical model. For lifting and

Table 2 Variance components of trunk flexion over 20°, trunk flexion over 45°, and lifting and carrying loads over 10 kg, expressed in percentage work time for the group approach

(n = 212)	S^2_{bg}	S^2_{bs}	S^2_{ws}
Trunk flexion over 20°	3.2 (1.3%)	94.1 (40.1%)	137.8 (58.6%)
Trunk flexion over 45°	2.8 (6.8%)	12.0 (29.8%)	25.5 (63.4%)
Lifting and carrying loads over 10 kg	0.7 (9.4%)	0.6 (8.4%)	6.2 (82.2%)

S^2_{bg}, between group variance; ‡S^2_{bs}, between subject variance; §S^2_{bs}, within subject variance.

Table 3 Corrected and uncorrected logistic regression estimates for the associations of trunk flexion over 20° and 45° and lifting and carrying over 10 kg with the risk of low back pain using the individual approach and group approach of observations

	OR (95% CI)			
	Individual approach, corrected for measurement error* (SSI, n = 212)	Individual approach (SSI, n = 212)	Group approach (SSG, n = 212)	Group approach (WSG, n = 769)
Trunk flexion over 20°				
% work time (unit is 5%)	0.91	0.93 (0.79 to 1.10)	1.00 (0.52 to 1.93)	0.94 (0.64 to 1.40)
Work hours per week	0.91	0.93 (0.84 to 1.04)	0.93 (0.75 to 1.14)	0.95 (0.87 to 1.04)
Trunk flexion over 45°				
% work time (unit is 5%)	1.36	1.23 (0.86 to 1.78)	2.06 (0.73 to 5.86)	1.85 (1.07 to 3.20)
Work hours per week	1.06	1.04 (0.79 to 1.36)	1.18 (0.62 to 2.26)	1.22 (0.89 to 1.67)
Lifting and carrying loads over 10 kg				
% work time (unit is 5%)	1.18	1.08 (0.34 to 3.40)	1.26 (0.14 to 11.77)	4.09 (1.41 to 11.90)
Work hours per week	0.65	0.84 (0.37 to 1.90)	1.00 (0.24 to 4.10)	1.62 (0.84 to 3.12)

*Correction method based on Lui and colleagues.[9]

carrying between 0 and 7.5 minutes the OR was set at 1.00 (the reference category). Between 7.5 and 15 minutes an OR of 2.13 (95% CI 1.10 to 4.14) was found, and between 15 and 30 minutes of exposure an OR of 1.38 (95% CI 0.84 to 2.29), and more than 30 minutes of lifting and carrying resulted in an OR of 1.33 (95% CI 0.84 to 2.11).

Nested models (linear, quadratic, quadratic restricted spline, and quadratic spline) were compared to each other with the likelihood ratio test (see table 4). The restricted quadratic spline model described the dose-response relation between lifting and carrying loads over 10 kg and severe LBP significantly better than the linear and quadratic model and appeared the satisfactory model to reflect the dose-response patterns among the data. The quadratic spline with no restrictions appeared to be no improvement over the restricted spline. In fig 1 this restricted spline is presented and the ORs are in reference to exposure measured at the median of the lowest exposure category (12.5th centile) and corresponds to about 3.6 minutes of exposure to lifting and carrying. For 7.5 minutes of lifting and carrying loads per week an OR of 1.58 (95% CI 1.32 to 2.00) was found, for 15 minutes an OR of 1.71 (95% CI 1.17 to 2.49) was found, for 30 minutes of exposure an OR of 1.04 (95% CI 0.63 to 1.70) was found, and for 40 minutes of lifting and carrying loads an OR of 1.06 (95% CI 0.67 to 1.67) was found. With the spline the ORs up to 15 minutes changed in a much more regular way than with the categorical model; the differences between the two models were most striking at 7.5 and 15 minutes of exposure, the borders of the lowest two exposure categories.

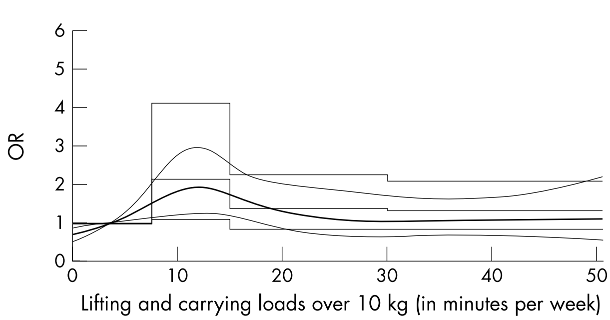

Figure 1 Restricted quadratic spline and categorical model for the relation between lifting and carrying loads over 10 kg and low back pain adjusted for age and psychosocial work demands. Odds ratios and 95% confidence intervals are in reference to the 12.5% centile (3.6 minutes of exposure).

Table 4 Comparison of the nested logistic models for the relation between physical workloads (lifting and carrying loads over 10 kg) and low back pain (method by Witte and Greenland[13])

Model	−2 log likelihood	Likelihood ratio*	Degrees of freedom	p value
Lifting and carrying loads over 10 kg (work hours per week)				
Intercept only	721.5			
Linear	711.1	10.4†	1	0.02
Quadratic	707.0	4.1‡	1	0.04
Quadratic spline restricted both tails	703.3	3.7§	1	0.05
Quadratic spline	700.5	2.8¶	2	0.25

*Likelihood ratio statistic (χ^2) comparing the nested models.
†Compared to the intercept only model.
‡Compared to the linear model.
§Compared to the quadratic model.
¶Compared to the quadratic spline restricted both tails.

For trunk flexion over 20° and trunk flexion over 45° comparable results were found; the quadratic spline model (with restrictions) appeared to be the most satisfactory model to reflect variations among the data. (Likelihood ratio test results not presented.) The associations appeared to be described by an upward arc shaped curve; increasing exposure resulted in increasing risk of back problems followed by a decreasing risk. However, the ORs for severe LBP over the range of exposure were not statistically significant.

DISCUSSION

To identify quantitative dose-response relations between physical workload and severe LBP, quantitative characterisation of physical load and determination of the nature of the relation between physical load and severe LBP are essential. In the present study we evaluated the effects of measurement strategy and the choice of statistical models on the dose-response relations between physical workloads and severe LBP.

Measurement approach

When establishing dose-response relations for back disorders, assessment of physical load should be able to result in valid estimates of workers. Direct observation techniques may meet this requirement when a sufficient number of exposure assessments is performed. In general, two measurement approaches can be identified: the individual approach and the group approach.

It appeared that for all physical load factors the within subject variance captured a much larger part of the total variance than the between subject variance, especially for lifting and carrying loads over 10 kg. This implies that many measurements are necessary to arrive at valid estimates of exposure to these physical factors for a given subject. For example, a variance ratio of 1.4 for trunk flexion over 20° implies that 12 repeated measurements are necessary to obtain an estimate with a reliability of 90%.[3] Assigning workers to predefined groups with the group approach resulted in a small reduction of the between subject variance since less than 10% of the total variation in exposure was captured by the between group variance. This variance analysis strongly suggested that the predefined occupational groups (by job title) did not reflect distinguishable exposure profiles of physical workloads.

The individual approach and attenuation
With the individual approach the differences in variance ratios among the physical load factors are reflected by the degree in attenuation of the dose-response relations of these factors. When the corrected estimates of the dose-response relations were used as a reference, the point estimates for the effect of lifting and carrying loads over 10 kg were mostly affected by attenuation, followed by trunk flexion over 45°. Trunk flexion over 20° was not notably affected by attenuation. With the introduction of the individual work hours per week to create the cumulative measure of exposure the variance ratios were not changed significantly (data not shown), and hence the degree of attenuation was comparable for exposure expressed in percentage work time and work hours per week.

The group approach versus the individual approach
In the present study, the group approach (SSG) resulted in stronger associations for trunk flexion over 45° and lifting and carrying loads over 10 kg expressed in percentage work time than the individual approach (SSI). In general, attenuation resulting from the group approach is a fraction of the attenuation resulting from the individual approach.[5] However, since in the present study the groups explained less than 10% of the total variance of physical load the stronger associations of the group approach can hardly be explained by less attenuation. With reference to the estimates corrected for measurement error, it seems that the association for trunk flexion over 45° and lifting and carrying loads over 10 kg with the SSG group approach are even overestimated. Simulation studies[18 19] have shown that Berkson measurement error (as is the case with the group approach) may result in bias in logistic and log-linear models with dichotomous outcomes. The bias is away from the null in estimating dose-response relations when, among others, the groups' variance of exposure increases with the groups' mean of the exposure. The correlation coefficient between the mean and the standard deviation of the percentage of work time in trunk flexion over 45° among the different occupational groups was 0.90, and for lifting and carrying loads over 10 kg, 0.97. Furthermore, the estimates for exposure to physical load expressed in percentage of work time bias may also have affected the estimates for the cumulative exposure expressed in work hours per week. Simulation studies have shown that when cumulative measures of exposure are used that are a combination of data at a group level and individual level, estimates may be biased away or towards unity.[19]

The group approach; the whole study population versus the observed subset
In contrast to the group approach applied on the subset of observed individuals (SSG) the group approach applied on the whole study population (WSG) showed statistically significant associations which are the result of the larger study population that allowed more precise estimates of the associations. The largest differences in odds ratios between SSG and WSG were observed for lifting and carrying. From a theoretical point of view, the exposure parameter with the lowest occurrence will have the highest misclassification since levels close to zero will be (too) difficult to assess accurately.

Trunk flexion over 45° and lifting and carrying loads showed significant associations expressed in percentage of work time, whereas these factors were not significant when expressed in work hours per week. Besides the possibility of bias due to the cumulative measure of exposure (as mentioned above), the disappearance of significant associations can also be explained by the fact that subjects who worked 40 or more hours per week experienced less severe LBP (OR 0.30, 95% CI 0.09 to 1.03 in reference to subjects working less than 20 hours per week). In particular a negative association between work hours and severe LBP was found in the group of workers with the highest exposure to physical load (expressed in percentage work time). Hence, in the present cross sectional study the results are indicative of a healthy worker effect where subjects without severe LBP experience longer work weeks than subjects with severe LBP.

Nature of dose-response relations
A hierarchy of nested logistic regression models[13] was used to determine a model rich enough to capture patterns of exposure and associated risk among the data. In comparison with the linear and quadratic models, the restricted quadratic spline models fitted the dose response relations between the three physical load factors and severe LBP among the data best. The associations between trunk flexion over 20° and 45° and severe LBP were described by an upward arc shaped curve; however, the associations were not statistically significant. For lifting and carrying loads over 10 kg the upward arc shaped curve representing significant associations up to 18 minutes of exposure was followed by associations close to unity. In contrast to these upward arc shaped curves, some authors have stated that absence of any physical load as well excessive physical load is considered a risk for back problems, as described by a U-curve.[10 11] As shown above, subjects without severe LBP worked more hours per week than subjects with severe LBP, especially among groups that are exposed to high physical load for a large percentage of their work time. This healthy worker effect resulted in the negative trend of the dose-response curve for the cumulative calculated exposure to physical load expressed in work hours per week.

The quadratic spline was compared with the more traditional approach of dose-response analysis, the categorical model. The categorical model results in dose-response associations that follow a stepwise pattern with abrupt changes in risk at the transition of one exposure category to the other. The most dramatic change in risk caused by a small change in exposure was found for exposure to lifting and carrying up to 15 minutes per week. In contrast with the categorical model, the quadratic spline model is able to pick up variation among the data within categories and the shape of the dose-response curve is therefore less sensitive to the choice of cut off points for the categories as additional analysis showed (results not presented). In the present study, the resulting dose-response curve was a more realistic representation where a small change in exposure resulted in a small change in the risk of severe LBP. Such a smooth curve allows identification of thresholds of exposure where exposure to physical load really becomes an issue in the occurrence of severe LBP. However, the cross sectional nature of the present study limits the interpretation.

When only a few exposure categories can be defined due to a limited number of subjects in the study, splines may have an advantage over the categorical approach. The categorical analysis may not capture the pattern of the dose-response relations since large changes in risk may occur within the same broad exposure category. Therefore, spline models will probably have an advantage when dose-response relations are estimated with the individual approach because the number of subjects is often not very large, simply due to the fact that all subjects in the study have to be measured repeatedly. Since the individual approach was not the best approach to estimate individual exposure to physical load in the present study, we did not perform dose-response analysis on exposure data based on this approach.

When the group approach is used to assess exposure to physical load, spline models are only of use when these group estimates of physical load are multiplied by individual information, such as work hours per week, in order to reach for a continuous exposure scale. (With the group approach only as many different exposure values exist as there are occupational groups.) However, in the present cross sectional analysis this cumulative exposure duration was affected by bias due to a healthy worker effect.

Conclusions

In the present study two features of dose-response modelling were scrutinised: the measurement strategy of the exposure and the nature of the dose-response relation defined by statistical models. One has to realise that choices in study design, sample size, and handling of bias and confounding are important when dose-response relations are determined. Although there are limitations to drawing conclusions from one dataset, the present study showed that the choice for a particular measurement strategy of physical load influenced the strength of the associations between physical load and severe LBP. Furthermore, statistical models that anticipate a linear relation between physical load and severe LBP may be unable to identify patterns of exposure and associate risks among the data when applied over the whole exposure range. Categorical models also have drawbacks, since broad categories of exposure may not reflect relevant effects of physical load on severe LBP. It has to be noted that it is of major importance to obtain valid estimates of exposure to physical load before the nature of the dose-response relations is investigated; without valid estimates this is of no use. However, when indeed valid estimates of physical workload are obtained, this enormous measurement effort requires statistical techniques that make full use of the informational content. Hence, spline models are a promising approach to identify quantitative dose-response patterns between physical load and LBP.

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