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**Model for the work-relatedness of low-back pain**

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**Key terms:** low-back pain; meta-analysis; model; risk factor; work-relatedness

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# Model for the work-relatedness of low-back pain

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**Objectives** This study aimed at developing a model for determining the work-relatedness of low-back pain for a worker with low-back pain using both a personal exposure profile for well-established risk factors and the probability of low-back pain if the worker were unexposed to these factors.
**Methods** After a systematic review of the literature, the pooled prevalence of low-back pain in an unexposed population and the pooled odds ratio (OR) for each risk factor was calculated in a meta-analysis using a random effect model. An unbiased risk estimate for each risk factor was obtained by correcting the pooled OR for confounding by other risk factors. The probability of low-back pain was calculated with a logistic regression model. The input was (i) the age-dependent prevalence when not exposed and (ii) the unbiased risk estimates per risk factor of low and high exposure. The etiologic fraction was calculated to determine the level of work-relatedness.
**Results** The pooled prevalence for low-back pain among unexposed subjects was 22%, 30%, and 34% for the <35-year, 35-to-45-year, and >45-year age categories, respectively. The pooled OR was 1.51 [95% confidence interval (95% CI) 1.31–1.74] for manual materials handling, 1.68 (95% CI 1.41–2.01) for frequent bending or twisting, 1.39 (95% CI 1.24–1.55) for whole-body vibration, and 1.30 (1.17–1.45) for job dissatisfaction. For high exposure to manual materials handling, frequent bending or twisting, and whole-body vibration, the pooled OR was 1.92, 1.93, and 1.63, respectively.
**Conclusions** The model is the first that estimates the probability of work-relatedness for low-back pain for a given worker with low-back pain seen by a general practitioner or an occupational health physician.

**Key terms** meta-analysis, risk factors.

In the process of unraveling the multifactorial etiology of back disorders and the specific contribution of work-related risk factors, epidemiologic surveys have identified various individual, psychosocial, and physical risk factors. Manual materials handling, frequent bending or twisting of the trunk, whole-body vibration, and high physical workload have been well established as physical risk factors of low-back pain (1–3). Although psychosocial factors are far less clear in the etiology of low-back pain, job dissatisfaction, and monotonous work seem to be important factors contributing to the occurrence of low-back pain (1, 4–5). These risk factors have been addressed in several recommendations in national and international occupational health guidelines with the aim of avoiding or diminishing the occurrence of work-related low-back pain (6–9). However, occupational health guidelines are compiled for a general working population and cannot directly determine the work-relatedness of low-back pain with respect to an individual worker who suffers from low-back pain.

Clinical decision theory provides a methodology with which to apply these general recommendations on an individual level by using a decision rule model (10–12). The application of decision rule models has long been advocated in clinical practice [eg, in cardiac surgery (13)].

Thus the use of clinical decision theory allows the likelihood of a worker's low-back pain being due to work-related risk factors to be estimated so that the probability of low-back pain if the person were not exposed to these risk factors is taken into consideration. Thus far, no model within general and occupational medicine takes into account crucial work-related risk factors and can be used to help determine the level of

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work-relatedness of low-back pain for an individual worker. A more-accurate determination of the work-relatedness of low-back pain may enable occupational health practitioners to intervene more appropriately in the relationship between the worker and the work environment.

The purpose of this study was to develop a model for estimating the level of work-relatedness of low-back pain for an individual worker, taking into account the personal exposure profile to established risk factors for low-back pain.

## Methods and assumptions of the model

### Data from the literature

Extensive searches of available literature concerning work-related risk factors for low-back pain have recently been published (1, 3). For our present study, a selection of these data was made using the following inclusion criteria: (i) articles describing the occurrence of nonspecific low-back pain in terms of a period prevalence of ≤1-year or a 1-year incidence, (ii) articles reporting associations between nonspecific low-back pain and exposure to work-related physical or work-related psychosocial risk factors. To update the available information, a literature search was made from January 2000 to September 2002 in the MEDLINE and EMBASE databases using the following strategy: low-back pain AND risk factors (AND (lifting OR posture OR vibration OR workload OR job satisfaction OR monotonous work).

Studies were excluded if the exposed population was exposed to risk factors at a level below the predetermined cutoff points. In accordance with internationally accepted guidelines (6, 9), the following cutoff points were used: manual materials handling requires frequent lifting of 5 kg or lifting of >25 kg more than one time a day (including patient handling), frequent bending or twisting of the trunk to >20 degrees for >2 hours a day, whole-body vibration of >0.5 m/s$^2$ during a workday, whereas high physical workload, job dissatisfaction, and monotonous work were dichotomous variables (ie, yes or no). Any disagreement regarding study inclusion and exposure assessment were resolved by consensus among the authors.

### Data extraction

The analysis focused on associations between the occurrence of low-back pain and age, manual materials handling, frequent bending or twisting of the trunk, whole-body vibration, high physical workload, job dissatisfaction, and monotonous work. Risk estimates were expressed as odds ratios (OR) or relative risks. Whenever possible, the risk estimate of these risk factors was retrieved from the original article, as were the variables that were adjusted for in the statistical analysis. In several publications this information was not presented, but, for all the studies that provided sufficient raw data for 2×2 tables, risk estimates were calculated with 95% confidence intervals (95% CI).

### Prevalence of low-back pain for persons when unexposed

The prevalence of low-back pain among unexposed persons was extracted from the unexposed populations of the included studies. To calculate the probability of having low-back pain, we determined a pooled prevalence for the unexposed persons, weighted by study size. The weighted pooled prevalence from the meta-analysis was assumed to represent the prevalence of low-back pain among the age category 35–44 years, which can be considered the mean age category in the general working population. Several studies have indicated an age effect in the prevalence of low-back pain (1, 14, 15). To take this age effect into account, we selected studies that described the effect of age in multivariate models adjusted for other risk factors for low-back pain. We then conducted a meta-analysis to obtain unbiased risk estimates for the described age categories, using the age <35 years as a reference category. The weighted pooled prevalence and the unbiased risk estimates for the age categories 35–44 years and >45 years were used to assess the probability of low-back pain in three age categories for the unexposed workers.

### Meta-analysis

A meta-analysis was conducted on the risk factors manual materials handling, frequent bending or twisting of the trunk, whole-body vibration, high physical workload, job dissatisfaction, and monotonous work (1–3). A preliminary analysis revealed that the homogeneity statistic was significant for all the risk factors, meaning that the risk estimates were heterogeneous between studies, compared with the variance within the studies involved. Therefore, we used a random effects model to calculate a pooled risk estimate for each risk factor (16, 17).

In order to obtain an unbiased risk estimate for each risk factor, we divided the study results into adjusted and unadjusted risk estimates by defining adjusted risk estimates as the estimates adjusted for one of the other risk estimates used in the meta-analysis. When no significant differences were detected between the unadjusted and adjusted risk estimates, they were pooled. In case of a significant difference, the unadjusted risk factor was corrected for other risk factors by a correction factor before being pooled (18, 12). This correction factor was calculated from studies describing both unadjusted and adjusted risk estimates for the same risk factor by subtracting the unadjusted ln(OR) from the adjusted ln(OR) for that risk factor. The correction factor was added to the ln(OR) of the studies, using unadjusted estimates for that particular risk factor (18, 12). Finally, the unbiased risk estimates were pooled.

### *Magnitude, frequency and duration of exposure*

For the studies describing more than one risk estimate for a risk factor taking into account the magnitude, frequency, or duration of exposure, the lowest value above the defined cut-off point was selected as the initial input in our meta-analysis. Subsequently, a more-detailed analysis was conducted for the studies that included estimates for both low and high exposure to the distinguished risk factors. For these studies pooled risk estimates for low and high exposure were calculated, as well as the risk ratio of high versus low exposure, using the same strategy as has already been described. Multiplying this risk ratio with the pooled risk estimate from the general meta-analysis resulted in the risk estimate for high exposure per risk factor to be used in the model.

### *Model development*

The basis of the model was the probability of low-back pain for persons unexposed to the risk factors under study. The probability equals the prevalence among unexposed subjects calculated in the meta-analysis. The probability of low-back pain can be increased when exposure to one or more risk factors is present. The adjusted estimates per risk factor from the meta-analysis were used as input into the model. Hence the probability for low-back pain could be calculated with the following formula:

$$p_x = \frac{1}{1 + \{\exp - [\varepsilon + 1\text{n}(\vartheta_{het_1}) + 1\text{n}(\vartheta_{het_2}) + .... + \ln(\vartheta_{het_i})]\}}$$

$$\text{with } \varepsilon = \ln [p_a / (1-p_a)],$$

where $p_a$= age-dependent prevalence of low-back pain when not exposed and $\hat{\vartheta}_{het}$ = effect size of a risk factor.

The final calculated probability presents the likelihood for the occurrence of low-back pain given the combination of risk factors present.

The model is presented as a score chart, with rounded values of $10\times\ln(OR_{adjusted})$ per risk factor as scores (13). For example, a pooled $\ln(OR_{adjusted})$ of 0.42 would result in a score of +4 in the prediction chart. The total sum score of the risk factors present corresponds to the probability of low-back pain developing in that specific case. In order to determine the level of work-relatedness, we used the etiologic fraction or attributable risk percentage (ie, the percentage of the overall risk for low-back pain that is related to exposure to the risk factors within the model (19).

## Results

### *Data from the literature*

The two reviews focusing on risk factors and the occurrence of low-back pain included 44 studies (1, 3). Of these studies, 30 fulfilled the criteria for our analysis (20–50). Fourteen studies were rejected from further analysis for the following reasons: a health endpoint other than a period prevalence of ≤12 months or the incidence of low-back pain (N=9), lack of a clear exposure definition (N=2), or specific low-back pain such as disk prolapse and sciatica (N=3).

In addition to these 30 studies, 10 other studies were included after an additional literature search with the same criteria (51–60). Table 1 lists the features of the 40 studies included in the analysis.

### *Data extraction*

Table 1 summarizes the risk estimates for the factors under study. Of the 40 studies included, 35 had a cross-sectional design (including 10 population-based studies). Five studies had a longitudinal design. The ratio of unadjusted to adjusted studies was 15:3 for manual materials handling, 7:8 for frequent bending or twisting of the trunk, 8:5 for whole-body vibration, 7:1 for high physical workload, 8:1 for job dissatisfaction, and 4:1 monotonous work.

### *Prevalence of low-back pain among unexposed persons*

The weighted pooled prevalence for the occurrence of low-back pain among unexposed persons was 30%, resulting in a probability of P=0.30 for low-back pain for unexposed persons. This prevalence represents the probability of low-back pain in the age category 35–44 years as indicated by the meta-analysis. The risk estimates for age categories 35–44 years and >45 years are presented in table 2. From the weighted pooled prevalence of 30% and these risk estimates, we calculated a probability of low-back pain of 22% for unexposed subjects of ≤35 years of age and a probability of 34% for unexposed persons >45 years of age.

**Table 1.** Characteristics of the included studies (N=40). When odds ratios (OR), or relative risks, are presented in both boldface and italics, they have been adjusted for each other; odds ratios or relative risks presented only in italics are adjusted for one of the other risk factors, but no value for those risk factor(s) is given. When both the adjusted and unadjusted OR are given, the adjusted was used in the meta-analysis. (95% CI=95% confidence interval, NA = not applicable)

| Authors | Design | Study population | Manual materials handling | | Frequent bending and twisting of the trunk | | Whole-body vibration | | High physical workload | | Job dissatis-faction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OR [a] | 95% CI | OR [a] | 95% CI | OR [a] | 95% CI | OR [a] | 95% CI | OR [a] | 95% CI |
| Alcouffe et al, 1999 (49) | Cross-sectional | 7010 workers (male & female) | ***1.4*** | ***1.2–1.6*** | ***2.0*** | ***1.7–2.3*** | ***1.3*** | ***1.7–2.2*** | · | · | · | · |
| Arad & Ryan, 1986 (22) | Cross-sectional | 831 nurses (female) | 2.7 [b] | 1.8–4.1 | · | · | · | · | · | · | · | · |
| Bigos et al, 1991 (31) | Prospective cohort | 1631 workers in a Boeing company factory (male & female) | · | · | · | · | · | · | · | · | 1.7 | 1.3–2.2 |
| Boshuizen et al, 1990 (28) | Cross-sectional | 450 tractor drivers & 110 agriculture workers (male) | · | · | · | · | 1.5 | 1.0–2.1 | · | · | · | · |
| Boshuizen et al, 1992 (34) | Cross-sectional | 242 drivers & 210<br>operators (male) | ·<br>· | ·<br>· | ·<br>· | ·<br>· | *1.3*<br>1.7 | *0.6–2.6*<br>1.1–2.8 | ·<br>· | ·<br>· | ·<br>· | ·<br>· |
| Bovenzi & Zadini, 1992 (35) | Cross-sectional | 234 bus drivers & 125 maintenance workers (male) | · | · | ***2.3*** | ***1.2–4.3*** | ***3.6*** | ***1.6–8.2*** | · | · | · | · |
| Bovenzi & Betta, 1994 (38) | Cross-sectional | 1155 tractor drivers & 220 office workers (male) | · | · | ***2.0*** | ***1.2–3.5*** | ***1.6*** | ***1.0–2.4*** | · | · | · | · |
| Burdorf et al, 1991 (32) | Cross-sectional | 114 concrete workers & 52 maintenance workers (male) | · | · | 2.8 | 1.3–6.0 | 3.1 | 1.3–7.5 | · | · | · | · |
| Burdorf et al, 1997 (45) | Cross-sectional | 161 tank terminal workers | · | · | *1.1* | *1.0–1.2* | · | · | · | · | · | · |
| Estryn-Behar et al, 1990 (29) | Cross-sectional | 1505 nurses (female) | ***2.0***<br>2.6 | **NA**<br>1.8–3.7 | ***2.1***<br>2.8 | **NA**<br>1.9–4.1 | ·<br>· | ·<br>· | ·<br>· | ·<br>· | ·<br>· | ·<br>· |
| Gilad & Kirschenbaum, 1986 (23) | Cross-sectional | 250 mine workers (male) | 3.1 | 1.1–8.7 | · | · | · | · | · | · | · | · |
| Hartvigsen, 2001 (58) | Prospective cohort | 1397 Danish workers (male & female) | · | · | · | · | · | · | 1.7 | 1.2–2.3 | · | · |
| Heliövaara et al. (33) | Cross-sectional-population | 2946 Finnish women & 2727 Finnish men | · | · | · | · | · | · | 2.5 [b] | 1.4–4.7 | · | · |
| Holmström, 1991 (36) | Cross-sectional | 1772 construction workers | 1.1 | 1.0–1.3 | · | · | · | · | · | · | 1.4 | 1.1–1.7 |
| Hoogendoorn et al, 2001 (59); Hoogendoorn et al, 2000 (54) | Prospective cohort | 861 Dutch workers | ***1.6*** | ***1.0–2.7*** | ***1.3*** | ***0.8–2.2*** | · | · | · | · | ***1.8*** | ***1.0–3.2*** |
| Houtman et al, 1994 (39) | Cross-sectional–population | 5865 Dutch workers (male & female) | · | · | · | · | · | · | 1.6 | 1.4–1.9 | · | · |
| Kerr et al, 2001 (60) | Case-referent | 316 workers (male & female) in automobile industry | · | · | *1.7* | *1.0–2.9* | · | · | 3.0 | 1.8–5.4 | 1.7 | 1.2–2.5 |
| Kumar et al, 1999 (53) | Cross-sectional | 50 tractor driving farmers & 50 nontractor driving farmers | · | · | · | · | 2.6 | 1.1–6.2 | · | · | · | · |
| Latza et al, 2000 (56) | Cross-sectional–population | 770 German workers (male & female) | · | · | · | · | · | · | 1.8 | 1.1–2.9 | · | · |
| Latza et al, 2000 (55) | Cross-sectional | 571 construction workers (male) | 2.3 | 1.1–6.5 | · | · | · | · | · | · | · | · |
| Lau et al, 1995 (41) | Cross-sectional–population | 752 population study, Hong Kong households (male & female) | 2.3 | 1.9–2.7 | · | · | · | · | · | · | · | · |
| Leigh & Sheetz, 1989 (25) | Cross-sectional–population | 1414 American workers (male & female) | · | · | · | · | · | · | 1.7 | 1.1–2.9 | · | · |
| Liira et al, 1996 (43) | Cross-sectional–population | 8020 Canadian blue-collar workers (male & female) | 1.5 | 1.1–1.9 | 2.3 | 1.7–3.2 | 1.8 | 1.4–2.7 | · | · | · | · |
| Linton, 1990 (30) | Cross-sectional | 22180 Swedish workers (male & female) | 1.8 | 1.5–2.1 | 2.2 | 1.8–2.6 | 1.8 | 1.5–2.2 | · | · | · | · |
| Magnusson et al, 1996 (44) | Cross-sectional | 228 drivers & 137 sedentary workers (male) | 1.9 | 1.2–2.8 | · | · | 1.8 | 1.2–2.8 | · | · | · | · |
| Ory et al, 1997 (46) | Cross-sectional | 418 tannery workers (male) | 3.5 | 1.4–8.8 | · | · | · | · | · | · | · | · |
| Papageorgiou et al, 1997 (51) | Cross-sectional–population | 767 working population | · | · | · | · | · | · | · | · | 1.4 | 1.2–1.8 |
| Picavet & Schouten, 2000 (57) | Cross-sectional–population | 22 415 Dutch population (male & female) | ***1.2*** [c]<br>1.5 | ***1.1–1.3***<br>1.4–1.5 | ***1.6***<br>1.9 | ***1.5–1.8***<br>1.8–2.1 | ·<br>· | ·<br>· | ·<br>· | ·<br>· | ·<br>· | ·<br>· |
| Pietri et al, 1992 (37) | Cross-sectional | 1709 commercial travellers (male & female) | ***1.3*** | ***1.0–1.7*** | · | · | ***2.0*** | ***1.3–3.1*** | · | · | · | · |
| Van Poppel et al, 1998 (52) | Prospective cohort | 238 worker in cargo department of KLM | · | · | · | · | · | · | · | · | 1.2 | 1.1–1.4 |

(continued)

**Table 1.** Continued.

| Authors | Design | Study population | Manual materials handling | | Frequent bending and twisting of the trunk | | Whole-body vibration | | High physical workload | | Job dissatis-faction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | OR [a] | 95% CI | OR [a] | 95% CI | OR [a] | 95% CI | OR [a] | 95% CI | OR [a] | 95% CI |
| Saraste & Hultman, 1987 (24) | Cross-sectional–population | 2872 Swedish population (male & female) | 1.9 | 1.6–2.3 | 2.6 | 2.1–3.3 | 2.1 | 1.3–3.5 | · | · | · | · |
| Smedley et al, 1995 (42) | Cross-sectional | 1616 nurses (female) | 1.7 [b] | 1.1–2.3 [b] | · | · | · | · | · | · | · | · |
| Smedley et al, 1997 (47) | Prospective cohort | 961 nurses (female) | 1.7 [b] | 1.1–2.5 [b] | · | · | · | · | · | · | · | · |
| Suadicani et al, 1994 (40) | Cross-sectional | 469 steel plant workers (male & female) | 2.4 | 1.5–3.6 | 2.4 | 1.6–3.7 | · | · | · | · | · | · |
| Svensson & Andersson, 1983 (20) | Cross-sectional | 940 Swedish men | 1.7 | 1.1–2.6 | · | · | · | · | 1.5 | 1.0–2.4 | 2.0 | 1.2–3.2 |
| Svensson & Andersson, 1989 (26) | Cross-sectional | 1410 Swedish women | · | · | 1.4 | 1.1–1.8 | · | · | · | · | 1.4 | 1.1–1.8 |
| Waters et al, 1999 (50) | Cross-sectional | 284 industrial workers (male) | 2.1 | 1.1–4.0 | · | · | · | · | · | · | · | · |
| Wells et al, 1983 (21) | Cross-sectional | 196 letter carriers, 76 meter readers, 127 clerks (male) | 2.2 | 1.3–3.7 | · | · | · | · | · | · | · | · |
| Xu et al, 1997 (48) | Cross-sectional–population | 5940 workers (male & female) | · | · | ***1.7*** | ***1.5–1.9*** | ***1.3*** | ***1.0–1.6*** | ***1.3*** | ***1.1–1.5*** | · | · |
| | | | 1.6 | NA | 2.0 | 1.7 –2.4 | 1.8 | 1.2–2.7 | 2.2 | 1.6–3.9 | · | · |

[a] Risk estimate.
[b] Other value than in the original published review due to choice of other endpoint.
[c] Only used to calculate correction factor.

## *Meta analysis*

Table 2 presents the pooled unadjusted and adjusted risk estimates per risk factor. For all the risk factors the pooled risk estimate from the studies with adjustment for one of the other risk factors differed from the pooled estimate based on the studies without this adjustment. The corrected confounders were based on the available epidemiologic information in the studies that reported both the adjusted and the unadjusted risk estimates per risk factor. This procedure resulted in a correction factor of –0.2 for manual materials handling corrected for frequent bending or twisting of the trunk (29, 57), of –0.2 for frequent bending or twisting of the trunk corrected for manual materials handling (48, 57), of –0.3 for whole-body vibration corrected for manual materials handling and frequent bending or twisting of the trunk (34, 38, 48), of –0.5 for high physical workload corrected for manual materials handling and frequent bending or twisting of the trunk (48), of –0.6 for monotonous work corrected for job dissatisfaction and high physical workload (39), and of –0.1 for job dissatisfaction corrected for high physical workload (54). Subsequently, the corrected risk estimates and the adjusted risk estimates were pooled to obtain a final unbiased risk estimate for that risk factor (table 2). The final risk estimates of high physical workload and monotonous work were not significant and were thus not included in the model.

**Table 2.** Results of the meta-analysis for six occupational risk factors for low-back pain and the effect of age on low-back pain.

| Risk factor | Pooled risk estimate | | Pooled risk estimate after correction | | Overall pooled risk estimate | |
|---|---|---|---|---|---|---|
| | OR | 95% CI | OR | 95% CI | OR | 95% CI |
| Age | | | | | | |
| 35–45 years | | | | | | |
| Nine studies [a] | 1.47 | 1.19–1.82 | 1.47 | 1.19–1.82 | 1.47 | 1.19–1.82 |
| >45 years | | | | | | |
| Ten studies [a] | 1.78 | 1.42–2.22 | 1.78 | 1.42–2.22 | 1.78 | 1.42–2.22 |
| Manual materials handling | | | | | | |
| Fifteen studies [b] | 1.95 | 1.63–2.30 | 1.54 | 1.30–1.83 | 1.51 | 1.31–1.74 |
| Three studies [a] | 1.38 | 1.13–1.68 | 1.38 | 1.13–1.68 | · | · |
| Frequent bending and twisting of the trunk | | | | | | |
| Seven studies [b] | 2.20 | 1.82–2.66 | 1.80 | 1.49–2.18 | 1.68 | 1.41–2.01 |
| Eight studies [a] | 1.52 | 1.20–1.93 | 1.52 | 1.20–1.93 | · | · |
| Whole-body vibration | | | | | | |
| Eight studies [b] | 1.83 | 1.63–2.06 | 1.38 | 1.15–1.66 | 1.39 | 1.24–1.55 |
| Five studies [a] | 1.43 | 1.19–1.71 | 1.43 | 1.19–1.71 | · | · |
| High physical workload | | | | | | |
| Seven studies [b] | 1.69 | 1.52–1.89 | 1.03 | 0.92–1.15 | 1.13 | 0.96–1.33 [c] |
| One study [a] | 1.28 | 1.08–1.52 | 1.28 | 1.08–1.52 | · | · |
| Job dissatisfaction | | | | | | |
| Eight studies [b] | 1.39 | 1.16–1.68 | 1.29 | 1.16–1.45 | 1.30 | 1.17–1.45 |
| One study [a] | 1.75 | 0.96–3.19 | 1.75 | 0.96–3.19 | · | · |
| Monotonous work | | | | | | |
| Four studies [b] | 1.68 | 1.22–2.30 | 0.92 | 0.67–1.26 | 1.00 | 0.80–1.26 [c] |
| One study [a] | 1.35 | 1.10–1.64 | 1.35 | 1.10–1.64 | · | · |

[a] Adjusted
[b] Unadjusted
[c] Not significant.

**Table 3.** Analysis of studies presenting risk estimates for both low and high exposure.

| Risk factor | Number of studies | | | Overall pooled risk estimate | | | | Ratio (high or low risk estimate) | Risk estimate (high exposure in the model) |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Unadjusted | Adjusted | Low exposure | | High exposure | | | |
| | | | | OR | 95% CI | OR | 95% CI | | |
| Manual materials handling | | | | 1.27 | 1.00–1.62 | 1.61 | 1.26–2.05 | 1.27 | 1.92 |
| Frequent bending or twisting of the trunk | 3 | 2 | 1 | 1.14 | 0.85–1.52 | 1.31 | 0.92–1.87 | 1.15 | 1.93 |
| Whole-body vibration | 3 | 2 | 1 | 2.25 | 2.01–2.52 | 2.63 | 1.69–4.10 | 1.17 | 1.63 |

| Risk factors | Score if risk factor present | | Score |
|---|---|---|---|
| | Exposed | Highly exposed | |
| • Lifting or manual materials handling | +4 | +7 | .......... |
| • Frequent bending or twisting of trunk | +5 | +7 | .......... |
| • Whole-body vibration | +3 | +5 | .......... |
| • Low job satisfaction | +3 | ...... | .......... |
| | | Total score (0–22) | .......... |

| Total score | Age (years) | | |
|---|---|---|---|
| | <35 | 35–45 | >45 |
| | Etiologic fraction | | |
| 0 (no exposure) | 0 | 0 | 0 |
| 1 | 7 | 7 | 6 |
| 2 | 14 | 13 | 12 |
| 3 | 20 | 18 | 17 |
| 4 | 26 | 23 | 22 |
| 5 | 31 | 28 | 26 |
| 6 | 35 | 32 | 30 |
| 7 | 39 | 35 | 33 |
| 8 | 43 | 39 | 36 |
| 9 | 46 | 42 | 39 |
| 10 | 49 | 44 | 42 |
| 11 | 52 | 47 | 44 |
| 12 | 55 | 49 | 46 |
| 13 | 57 | 51 | 48 |
| 14 | 59 | 53 | 50 |
| 15 | 61 | 54 | 51 |
| 16 | 62 | 56 | 53 |
| 17 | 64 | 57 | 54 |
| 18 | 65 | 58 | 55 |
| 19 | 66 | 60 | 56 |
| 20 | 68 | 61 | 57 |
| 21 | 69 | 61 | 58 |
| 22 | 69 | 62 | 59 |

**Figure 1.** Flow chart to assess the level of work-relatedness of low-back pain. (Cutoff for "highly exposed" under "score if risk factor present": >15 kg for 10% of the worktime for manual materials handling, >10% of the worktime with back bent or twisted 30 degrees for frequent bending and twisting of the trunk, and 5 years' exposure to 1 m/s$^2$ or an equivalent vibration dose for whole-body vibration; horizontal lines under "Etiologic fraction" indicate the 50% level of work-relatedness of low-back pain)

### *Magnitude, frequency and duration of exposure*

Table 3 shows the results of the analysis on low and high exposure for the physical risk factors included in the model (ie, manual materials handling, frequent bending or twisting of the trunk, and whole-body vibration). Five studies mentioned both low and high exposure values for manual materials handling (44, 46, 49, 54, 55), three reported them for frequent bending or twisting of the trunk (36, 48, 54), and three gave them for whole-body vibration (28, 35, 38). The cutoffs that were used for high exposure were approximately >15 kg 10% of the worktime for manual materials handling, 30 degrees >10% of the worktime for frequent bending or twisting of the trunk, and 5 years of exposure to 1 m/s$^2$ or an equivalent vibration dose for whole-body vibration (28). For high exposure, the analysis resulted in a risk estimate of 1.92 for manual materials handling, 1.93 for frequent bending or twisting of the trunk, and 1.63 for whole-body vibration.

### *Model development*

The model was built on the age-dependent prevalence of low-back pain for persons when unexposed. The additional presence of one or more of the risk factors under study raised the probability. The transformation of the model into a flow chart yielded a score of +4, +5, +3, and +3 for manual materials handling, frequent bending or twisting of the trunk, whole-body vibration, and job dissatisfaction, respectively. When the risk estimates for high exposure to manual materials handling, frequent bending or twisting of the trunk, and whole-body vibration were considered, the high exposure scores in the flow chart resulted in +7, +7, and +5, respectively.

When no exposure to one of the risk factors under study was present, the chart score was 0 and resulted in the age-dependent prevalence for unexposed persons. From all possible scores, a concomitant probability for having low-back pain could be derived which was finally transposed into an etiologic fraction indicating the level of work-relatedness for low-back pain. Figure 1 shows the flow chart and the corresponding etiologic fractions per score.

## Discussion

In order to indicate the level of work-relatedness of low-back pain, we developed a model based of the epidemiologic information available from the literature. Techniques from clinical decision modeling enabled us to design a model that may help general practitioners and occupational health physicians determine the level of work-relatedness of low-back pain for an individual worker given the person's exposure profile to well-established risk factors.

### Heterogeneity

To minimize heterogeneity between studies, we used strict selection criteria for the studies to be included. Regarding case definitions, we used only studies of nonspecific low-back pain in terms of period prevalences. For exposure, we selected studies that had exposure to the risk factors of interest at a level above a predetermined cut-off point. Furthermore, we used a random effect model in our meta-analysis to adjust for heterogeneity in the study population. Most of the studies had a cross-sectional design. However, with regard to the estimated overall risk factors, we did not observe any differences in risks between cross-sectional and longitudinal studies.

### Age-dependent prevalences

The basis of the model is the age-dependent prevalence of low-back pain when persons are unexposed. The model is meant for use in situations in which a worker with low-back pain presents himself to a general practitioner or an occupational health physician. This objective might imply that using a point prevalence should give a better estimate for the age-dependent prevalence in that particular situation. However, most epidemiologic studies use period prevalences as the outcome. To verify the effect of using a point prevalence instead of a period prevalence, we calculated both measures of prevalence from two available data sets (61, 62). These data showed that, among the workers who had low-back pain in the previous 12 months, about 60% reported having had low-back pain in the previous 7 days. Thus, from these data, it appeared that the point prevalence roughly equals 0.6 times the period prevalence. However, using point prevalence in the model appeared to have a minor effect on the results of the model in terms of the etiologic fraction. For the consistency of the model, we chose to uphold the use of the period prevalence because the risk estimates of the included risk factors are primarily based on 12-month prevalences.

### Correcting unadjusted risk estimates

It is known that not taking into account confounding factors may lead to an overestimation of a certain risk factor (18). Using a multiplicative model, we determined an unbiased risk estimate for the risk factors by means of correction for other confounding risk factors. For this purpose we used a technique often employed in clinical decision modeling [ie, calculation of a correction factor for the unadjusted risk estimates (18, 12)]. For this purpose, we needed studies that reported both unadjusted and adjusted risk estimates for the same risk factor. However, few studies reported this information. The two studies determining the correction factor for manual materials handling and frequent bending or twisting of the trunk revealed almost the same value; the same applies to the correction factor for whole-body vibration. However, the correction factor for high physical workload, job dissatisfaction, and monotonous work could only be calculated from one study. The correction factor for high physical workload was rather high, resulting in a strong correction of the risk estimate (see figure 1). Although this might indicate an underestimation of the true risk estimate for high physical workload, the fact that exposure to manual materials handling and frequent bending or twisting of the trunk strongly influences self-reported high physical workload (1) justifies the calculated correction factor.

To gain better insight into the effects of adjustment on the risk factors for low-back pain, we suggest that future studies present data on risk estimates in both unadjusted and adjusted analyses.

### Magnitude, frequency and duration of exposure

Several studies have indicated that the level of exposure to physical risk factors determines the occurrence of low-back pain (28, 63, 54). Unfortunately, there was little information available with which to split up exposure into magnitude, frequency, and duration. We therefore chose to select studies that described both low exposure and high exposure and used approximately the same cutoff for high exposure. Because of the low numbers in this analysis, the pooled risk estimates differed from those in the general meta-analysis. However, this difference was controlled by using the same studies for calculating pooled risk estimates for both low exposure and high exposure. For manual materials handling, we could derive low and high exposure values from five studies, using approximately the same cutoff for high exposure (ie, >15 kg for >10% of the worktime) (44, 46, 49, 54, 55). Because of the variation in exposure definition, it was difficult to give an exact cutoff for high exposure to manual materials handling. However, the cutoff that could be determined from the included studies corresponded within reason with recommendations considering manual materials handling (64).

For frequent bending or twisting of the trunk and whole-body vibration, we found three studies for the analysis, with a cutoff of approximately >30° bending or twisting >10% of the worktime for high exposure for frequent bending or twisting of the trunk (36, 48, 54) and that of 5 years of exposure to 1 $m/s^2$ or an equivalent vibration dose for whole-body vibration (28, 35, 38). The cutoff for frequent bending or twisting of the trunk corresponded well with data presented by Punnett et al (63). In their study, the odds ratio for frequent bending or twisting of the trunk increased significantly when the exposure duration was >10% of the cycle time. This study was not included in the meta-analysis because injury claims and physical examinations were used as the endpoint definition for low-back pain. High exposure to whole-body vibration could be quantified rather accurately because exposure to whole-body vibration was determined by direct measurements.

Regarding the foregoing discussion, we must consider that epidemiologic studies do not have sufficient power to measure all relevant dimensions. Incorporating information of a more biomechanical and physiological nature into the model might supplement the epidemiologic data and thus provide a more elaborate model, including magnitude, frequency, and duration of the distinguished risk factors (64).

### *Practical implications of the model*

The level of work-relatedness of low-back pain is indicated by the etiologic fraction (figure 1). To determine the likelihood of work-relatedness for the presented low-back pain dichotomously, we propose to use a cutoff point of 50%, meaning that, if 50% or more of the calculated probability is due to occupational exposure, the presented low-back pain can be regarded as work-related (see figure 1). An etiologic fraction of 50% is often used in decision making, for example, in compensating lung cancer patients occupationally exposed to hazardous agents such as asbestos (65).

In the model both low exposure and high exposure could be distinguished (figure 1). To put this distinction into practice, we suggest using the cut-off definitions described in this article. However, the choice for these cut-off values has influenced the estimated etiologic fraction due to a certain exposure. The sensitivity of our model for other definitions of exposure is difficult to evaluate, since most epidemiologic studies present risk estimates for exposed versus unexposed persons. For further development of the model, it would be advised for epidemiologic studies to report risk estimates for different levels of exposure.

It must be clear that the model is not an etiologic model for low-back pain; instead it is an attributive model for the effect of work on having nonspecific low-back pain. The model gives an estimate of the work-relatedness for the individual worker and can be used as a possible tool for directing intervention strategies. Furthermore, it must be emphasized that the presented model does not consider the nature and severity of low-back pain, such as low-back pain with sickness absence. The model only assesses the level of work-relatedness for an individual worker. Future longitudinal studies must determine the factors that predispose (eg, disability, chronicity, and sick leave) and the interaction between these factors and the factors in our model.

### *Concluding remarks*

The presented model enables general practitioners and occupational health physicians to estimate the level of work-relatedness of low-back pain for an individual worker. It may thus provide useful guidance as to the intervention to be proposed.

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