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Bias in risk estimates from variability of exposure to postural load on the back in occupational groups

by Alex Burdorf, MSc¹

BURDORF A. Bias in risk estimates from variability of exposure to postural load on the back in occupational groups. *Scand J Work Environ Health* 1993;19:50—4. Variability of exposure can be a source of information bias in studies with exposure assessment based on the use of a sample of workers in each occupational group under study. This paper presents a method to assess the rate of exposure misclassification from the magnitude of overlap of exposure distributions and, consequently, to evaluate the bias to risk estimates in cross-sectional and prospective studies. The percentage of work-time with trunk flexion and rotation was studied in five occupational groups. The rate of misclassification of exposure to trunk flexion and rotation varied from 0.03 to 0.35. Misclassification below 0.10 was found only for occupational groups with at least a 14-fold difference in mean exposure. Higher rates of misclassification can easily bias the risk estimates up to 50%. In the cross-sectional design the odds ratio was more sensitive to bias than the prevalence rate ratio. The estimate of the relative risk in a prospective study design was the least biased.

Key terms: epidemiology, measurement, misclassification of exposure.

Epidemiologic research is needed on the effects of workplace exposures on the occurrence of diseases in the working population. Investigations of low-back pain due to workplace exposures often have a cross-sectional design. In a cross-sectional study the prevalence of low-back pain is compared between groups of workers with respect to exposure status (1). In many surveys concerning low-back pain, the information on exposure status is obtained from self-administered questionnaires (2). If exposure to postural load is determined by reports provided by the workers, considerable misclassification of exposure is almost inevitable.

Studies on the reliability of questionnaires have consistently shown that self-reported aspects of postural load are in poor agreement with the results of more objective measurements (3—5). This source of misclassification of exposure, when independent of disease status, will generally bias the effect estimate towards the null value (1, 6). To reduce the measurement error, several methods have been advocated for objectively measuring postural load under work conditions (7—9). The application of these measurement techniques in occupational studies will markedly reduce measurement error and, as a consequence, reduce the potential bias due to nondifferential misclassification of exposure.

However, information bias can also occur as a result of the measurement strategy applied. The common approach in cross-sectional studies on low-back pain is to monitor a sample of workers in each occupational group under study. When exposure assessment is not possible for each individual, measurements of postural load are used to assign exposure categories to the occupational groups, often on the basis of the workers' mean exposure (2). Subsequently, the prevalence of low-back pain is compared among groups with different exposure status. In this grouping strategy, inherent misclassification of exposure will occur if the occupational groups show overlapping distributions of mean exposures in each occupational group. A similar problem may arise in prospective studies on incident cases of low-back pain in occupational groups when a random sample of workers in each occupational group is being monitored.

Therefore, variability of exposure among workers within an occupational group can be described in terms of nondifferential misclassification of exposure. Hence, it is important to know the magnitude of overlap of the exposure distributions. In this paper, the rate of nondifferential misclassification of exposure due to variability of the exposure among workers has been derived from the magnitude of the overlap in exposure experience of two occupational groups. Its impact on the estimate of the association between postural load and low-back pain was investigated. The purpose of the analysis was to assess the potential magnitude of bias caused to the risk estimate by exposure assessment based on grouping strategies in cross-sectional and prospective studies.

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Methods

In cross-sectional studies, the prevalence odds ratio is frequently used to derive a measure of association between exposure and disease. Some authors give preference to the prevalence rate ratio when the prevalence of disease is rather high (10). Since this condition is often true in studies of low-back disorders, for the purpose of the discussion, the effect of exposure misclassification on both measures of risk have been presented.

Exposure misclassification is expressed in table 1 by a 2×2 table of conditional probabilities (11). On the assumption of nondifferential misclassification with regard to exposure status, the probability of being classified correctly as exposed (P_{11}) should be equal to the probability of being classified correctly as unexposed (P_{00}). P_{11} is often referred to as exposure sensitivity, and P_{00} as exposure specificity (11). Under the assumption that the correct classification rate of the exposed and unexposed will be equal (that is $P_{11} = P_{00}$), the magnitude of nondifferential misclassification due to exposure variability can be derived from the overlap of exposure distributions of the two occupational groups compared. The probability of a measurement among the unexposed subjects exceeding or equaling a specific value is supposed to be the same as the probability of a measurement among the exposed subjects falling below this value. Essential for estimating this probability is inference about the underlying distributions. The distribution of measurements of aspects of postural load on the back is described best by the log-normal distribution, characterized by the geometric mean (GM) and the geometric standard deviation (GSD) (12). Thus the probability can be obtained by the following equation:

$$\ln GM_0 + (\ln GSD_0)(t_\alpha) = \ln GM_1 + (\ln GSD_1) \cdot (-t_\alpha) \quad (\text{equation 1})$$

The value of t_α corresponds to the percentile of the distribution of the one-sided Student's t-statistic (13, 14). The corresponding probability of a measurement exceeding or equaling this percentile presents the estimate of the misclassification rate γ . Note that the misclassification rate γ is equal to $1 - P_{11}$.

As a simple illustration of the effect of exposure misclassification, consider the hypothetical data presented for a cross-sectional study in table 2. An occupational group of 200 (n_1) subjects with high exposure to postural load on the back is compared with an occupational group of 200 (n_0) subjects with low exposure to postural load on the back. The measure of disease is the 12-month prevalence of low-back pain. In this example the overall prevalence of low-back pain is 40% among the total population. The prevalence of low-back pain among the subjects with high exposure is a/n_1 ; among the subjects with low exposure it is c/n_0 . By definition, when the exposure misclassification is nondifferential with regard to

Table 1. Distribution of subjects by true and observed exposure status.

Observed exposure	True exposure	
	Yes (1)	No (0)
Yes (1)	P_{11}	P_{10}
No (0)	P_{01}	P_{00}

Table 2. True distribution of subjects with low-back pain and subjects without by exposure status of postural load in a cross-sectional design.

Exposure status	Subjects with low-back pain	Subjects without low-back pain	Total
High (1)	100 (a)	100 (b)	200 (n_1)
Low (0)	60 (c)	140 (d)	200 (n_0)

health status, the subjects with low-back pain and the subjects without low-back pain have the same exposure sensitivity and specificity. Moreover, in this approach, the exposure sensitivity and specificity are assumed to be equal and can be derived directly from the obtained rate of misclassification. Given the true distribution of the cases and referents by exposure status, and the common value S for exposure sensitivity and specificity, the observed values of the cell frequencies can be calculated by the following equations:

$$A = aS + c(1 - S), \quad (\text{equation 2})$$

$$B = n_1 - A, \quad (\text{equation 3})$$

$$C = cS + a(1 - S), \quad (\text{equation 4})$$

and

$$D = n_0 - C. \quad (\text{equation 5})$$

In these equations the rate of misclassification is estimated by $1 - S$. The observed values of the cell frequencies can be used to obtain the observed risk estimates. The biased odds ratio is estimated by:

$$OR_b = [A / (n_1 - A)] / [C / (n_0 - C)]. \quad (\text{equation 6})$$

The biased prevalence rate ratio is estimated by:

$$PRR_b = (A / n_1) / (C / n_0). \quad (\text{equation 7})$$

A similar approach can be described for a hypothetical prospective study, as presented in table 3. A group of workers with high exposure to postural load on the back is compared with an occupational group of workers with low exposure to postural load. Suppose the true incidence rates of low-back pain are 70 per 1000 person-years in the high-exposure group and 30 per 1000 person-years in the low-exposure group. The true distributions of cases and person-years are presented in table 3. Given these figures

Table 3. True distribution of incident cases of low-back pain and exposure to postural load in a prospective design.

Exposure status	Incident cases of low-back pain	Person-years
High (1)	350 (a)	5000 (n_1)
Low (0)	180 (b)	6000 (n_0)

and the common value S for exposure sensitivity and specificity, the observed number of cases and subsequent person-years of exposure can be calculated by the following equations:

$$A = aS + b(1 - S), \quad (\text{equation 8})$$

$$B = bS + a(1 - S), \quad (\text{equation 9})$$

$$N_1 = n_1S + n_0(1 - S), \quad (\text{equation 10})$$

and

$$N_0 = n_0S + n_1(1 - S). \quad (\text{equation 11})$$

The biased relative risk is estimated by:

$$RR_b = (A/N_1)/(B/N_0). \quad (\text{equation 12})$$

Empirical data of a survey on workers' distributions of exposure to postural load in five different occupational groups have been used to estimate different rates of misclassification. The principle measure of exposure was the percentage of worktime with trunk flexion or trunk rotation (12). Straddle-carrier drivers were found to be the occupational group with the lowest exposure to trunk flexion, and crane operators formed the occupational group with the lowest exposure to trunk rotation. The magnitude of the overlap of the workers' exposure distributions has been calculated for each occupational title group,

the group with the lowest exposure being used as the reference.

To investigate the effect of exposure misclassification on the risk estimates in a cross-sectional study, an overall prevalence of low-back pain of 40% among the 200 subjects in the high-exposure group and 200 subjects in the low-exposure group was used. Different distributions of workers with low-back pain by exposure status were evaluated, which yielded values of true odds ratios close to 1.50, 2.25, and 3.00, and associated true prevalence rate ratios. For three rates of misclassification the biased odds ratios and prevalence rate ratios were calculated. An analogous analysis was made for a prospective design using hypothetical data according to the format of table 3. The true relative risks were 1.50, 2.33, and 3.00, and the same three rates of misclassification were evaluated.

Results

In table 4 the workers' distributions of exposure to trunk flexion and trunk rotation are presented, characterized by their geometric mean and geometric standard deviation. With regard to exposure to trunk flexion, the group of straddle-carrier drivers was used for reference. When the four occupational title groups were compared with this reference group, the application of equation 1 yielded rates of misclassification varying from 0.15 to 0.35. For exposure to trunk rotation the rates of misclassification varied from 0.03 to 0.31, when the four occupational title groups were compared with the group of crane operators. It can also be noted that considerable rates of misclassification can occur, although the occupational title groups can have clearly different values of workers' mean exposure to trunk flexion or trunk rotation.

In table 5 hypothetical data similar to the data given in table 2 have been used to illustrate the ex-

Table 4. Misclassification of exposure to postural load because of an overlap of distributions of percentage of worktime with trunk flexion and trunk rotation among occupational title groups. (GM = geometric mean, GSD = geometric standard deviation, df = degrees of freedom, t_α = value of t distribution, γ = misclassification rate)

Occupational title group	Exposure to trunk flexion					Exposure to trunk rotation				
	GM	GSD	df	t_α	γ	GM	GSD	df	t_α	γ
Straddle-carrier drivers	3.0	3.9	—	—	—	35.9	1.6	80	1.91	0.03
Crane operators	26.8	2.2	80	1.02	0.16	1.8	3.0	—	—	—
Office workers	22.0	1.7	60	1.05	0.15	4.7	2.4	58	0.49	0.31
Woodworking machinists	8.0	3.0	68	0.40	0.35	6.6	2.7	66	0.62	0.27
Packers	10.6	1.6	64	0.69	0.25	25.3	1.5	64	1.76	0.04

Table 5. Bias to the true odds ratio and the true prevalence rate ratio because of nondifferential misclassification of exposure in a cross-sectional design. (γ = misclassification rate)

True odds ratio (OR)	Biased odds ratio (OR_b)			True prevalence rate ratio (PRR)	Biased prevalence rate ratio (PRR_b)		
	$\gamma = 0.1$	$\gamma = 0.2$	$\gamma = 0.3$		$\gamma = 0.1$	$\gamma = 0.2$	$\gamma = 0.3$
3.05	2.42	1.93	1.55	1.96	1.70	1.48	1.30
2.23	1.89	1.61	1.37	1.62	1.47	1.33	1.21
1.52	1.40	1.28	1.18	1.29	1.22	1.16	1.11

tent of bias due to nondifferential misclassification of exposure in a cross-sectional study. The true odds ratio for low-back pain due to aspects of postural load was obtained simply from the marginal totals of a 2×2 table. When nondifferential misclassification of exposure is accounted for, the true odds ratio markedly decreases. For example, the true odds ratio is 2.23, whereas the observed odds ratio under the condition of 10% misclassification of exposure is only 1.89. Two points are noteworthy. First, when the true odds ratio increases, the bias introduced by the misclassification of exposure also increases. Second, higher rates of misclassification more strongly bias the odds ratio towards unity. With regard to the true prevalence rate ratio, the magnitude of the bias to the prevalence rate ratio also depends on the actual prevalence of the health outcome. The degree to which the prevalence rate ratio is underestimated is smaller than the bias in the odds ratio.

In table 6 the bias to the relative risk in a prospective study design is illustrated. Again, the observed relative risk decreases with a higher rate of misclassification. The magnitude of the bias in the estimated relative risk in the prospective design is slightly less than that of the bias in the estimated prevalence rate ratio in the cross-sectional design.

Discussion

Frequently, in occupational epidemiology on low-back disorders, the prevalence of these disorders is compared between occupational title groups. Whenever objective measurement techniques for postural load have been used, a random sample of workers in each occupational group is often monitored. The average values of the parameters measured are used to characterize the exposure to postural load in the occupational title groups (2). In fact, workers who have not been monitored are assigned the mean exposure of their occupational group.

Two occupational groups can have significantly different values for their mean exposure and thereby suggest a clear difference in exposure status. However, large variability of exposure within each group can result in overlapping exposure distributions and thus in misclassification of exposure. The variability of exposure within each occupational group is due to within-worker and between-worker variance. Information on the underlying distributions is essential for estimating the magnitude of the overlap. An extensive measurement program of the percentage worktime spent in trunk flexion and trunk rotation in five different occupational groups revealed that these aspects of exposure to postural load were best described by log-normal distributions (12). Hence, it was possible to draw inferences about the magnitude of overlap between two exposure distributions. The area of overlap presents a fruitful estimate of the rate of misclassification of exposure that is nondifferential to both exposure status and disease

Table 6. Bias to the true relative risk because of nondifferential misclassification of exposure in a prospective design. (γ = misclassification rate)

True relative risk (RR)	Biased relative risk (RR _b)		
	$\gamma = 0.1$	$\gamma = 0.2$	$\gamma = 0.3$
3.00	2.45	2.03	1.70
2.33	2.03	1.77	1.55
1.50	1.43	1.37	1.31

status. In this approach the nondifferential misclassification is solely due to the variability in exposure within an occupational group.

In this study the rates of misclassification of exposure to trunk flexion and rotation varied from 0.03 to 0.35. Misclassification below 10% was found only in comparisons of occupational groups with at least a 14-fold level of exposure, compared with the low-exposure group. The high rates of misclassification reflect the considerable variance in exposure between workers in the same group and between parts of a shift within workers (12). Under the assumption that the exposure variability and the concomitant concept of a log-normal distribution can be generalized to other occupational groups and work situations, misclassification of postural load due to nonneutral postures is easily obtained.

Attenuation of the risk estimate caused by exposure misclassification is demonstrated in tables 5 and 6. In the cross-sectional approach the odds ratio was more sensitive to bias than the prevalence rate ratio. The relative risk in the prospective approach showed the least bias. In the case of a dichotomous exposure categorization nondifferential misclassification of exposure always biases a true effect toward the null value. The foregoing approach to estimate the amount of bias can be extended to the more general case of more than two exposure categories. In specific cases it can be demonstrated that the bias due to nondifferential misclassification of exposure is not necessarily downward when a polychotomous exposure measure is used (6).

In this study the misclassification of exposure was limited to a main measure of exposure to postural load and its effect on the risk estimate for this exposure. In many occupational situations workers are exposed to several risk factors of postural load, such as rotation of the trunk, lifting, and forceful movements. There is no reason to believe that misclassification of exposure to these confounding factors will not occur. An assessment of the possible effect of confounder misclassification can be achieved with a similar approach for evaluating the nondifferential misclassification of the main exposure variable. Recently, Ahlbom & Steineck (15) pointed out that misclassification of the confounding (exposure) factor can be of particular importance. In their example control for a confounding variable, subject to a considerable amount of misclassification, led to a strong overestimate of the true exposure-disease association

measured by the incidence rate ratio. This observation clearly shows that the influence of the variability of exposure on misclassification must not be restricted to the main exposure variable of interest, but should also include the confounding exposure variables.

This paper has attempted to demonstrate a practical approach for assessing possible bias in cross-sectional and prospective studies on the basis of a comparison of two occupational groups with overlapping exposure distributions. The approach is only valid when the exposure sensitivity and specificity are assumed to be equal. If this assumption is being met, the presented method allows a direct estimation of the extent of misclassification of exposure and its effect on the attenuation of the risk estimate. This approach only requires empirical data on the distributions of exposure in the occupational groups under study. The primary importance of the procedure is that the assessment of exposure misclassification may guide researchers towards improving measurement strategies to decrease the estimated rate of misclassification. In some studies the conclusion could be inevitable that grouping by job title is inadequate. In other studies it may be necessary to collect exposure data on the individual level. Of less importance is the application of this procedure to adjust or "correct" the observed effect estimate for the amount of exposure misclassification due to exposure variability. Simultaneous presentation of the observed risk estimates and the adjusted "true" risk estimates offers the reader insight into the bias associated with the sources of variability.

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