

Exposure assessment strategies for work-related risk factors for musculoskeletal disorders

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The design of assessment strategies depends on the risk factors of interest, features of the measurement device, feasibility considerations, and variation at the workplace. The selection of variables should permit specific etiologic inferences. Several researchers have combined different methods into a broad array of exposure measures. Other authors have converted inputs from disparate methods into a common exposure metric, varying from subjective ratings to quantitative measures such as compression forces in the lumbar back. The parameterization of an exposure variable should address the 3 principal exposure dimensions intensity, frequency, and duration. Standardized expressions of variation patterns of exposure have been suggested. An alternative approach is the modeling of exposure variability that allows for exposure assessment at the individual level. A related topic is the critical time window of risk factors for musculoskeletal disorders. This window not only requires detailed information of exposure events over time, but also appropriate characterization of episodic musculoskeletal problems.

Key terms epidemiology, exposure modeling, review.

Musculoskeletal disorders have been recognized as a major cause of sickness absence and disability among many occupational populations (1, 2). In spite of the large number of epidemiologic studies, the risk factors and etiology of most work-related musculoskeletal disorders are not well understood (2, 3). For back disorders there is ample evidence for a strong association with physical load, that is, manual materials handling, frequent bending and twisting, physically heavy work, and whole-body vibration. There is some evidence for an association between psychological factors and back disorders, but this evidence is not consistent across different studies and study designs (1, 4). However, it is difficult to quantify the exact levels of these factors at which an increase in musculoskeletal risk occurs. The sparse information on dose-response relationships is certainly not specific enough to provide detailed, quantitative guidelines for workplace and task design. Existing guidelines for

physical load at work have been derived from experimental studies based on short-term physiological, biomechanical, and psychophysical responses to physical load experienced during a limited period (5—7). There is little, if any, epidemiologic evidence to support or refute the appropriateness of these guidelines to prevent the development of back disorders in occupational populations.

Epidemiologic studies have shown disappointing progress in validating the contribution of the well-established factors in experimental research to the occurrence of back disorders. Among other reasons, one of the most important is the complexity of exposure assessment at the workplace in relation to the musculoskeletal disorders of interest. First, in musculoskeletal epidemiology, the exposure paradigm differs from the usual concept in occupational epidemiology whereby exposure refers to an agent or factor in the environment external to the worker. However, some risk factors, especially physical load,

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cannot be determined independently of the worker. For example, physical load is assessed by posture, movement, and the force resulting from the interaction between the physical work requirements forced upon the worker and the worker's capacity to adopt particular techniques to perform the assigned tasks. Hence the worker's interaction with the workplace plays a crucial role in the exposure characterization.

Second, most risk factors cannot be described by a single parameter; instead they encompass several parameters, which are combined into an exposure metric. For example, manual materials handling includes different components, such as lifting, pushing, pulling, and several characteristics of each component (eg, weight, frequency, and distances in a lifting task).

Third, the relationship between most work-related risk factors and the occurrence of musculoskeletal disorders, in particular back disorders, is not unidirectional with an increase in exposure linearly associated with an increase in risk. For example, when dose-response relationships are being developed for awkward postures and strenuous movements, a U-shaped curve probably better describes the nature of the associations; absence of any load is considered a risk, as is excessive load (2, 8).

Fourth, outcome measures in musculoskeletal epidemiology are commonly defined in terms of a symptomatic state, such as the occurrence of back pain and back-related disability, rather than as a verifiable clinical outcome, such as herniated lumbar disc. The most nonspecific is unfortunately the most common, pain. The non-specificity of pain as a health end point is a major drawback since it hampers the definition of specific parameters of exposure that relate to the underlying disease process.

Fifth, the temporal relationship between risk factors and musculoskeletal disorders often does not fit the model of a natural progress from minor ailments to severely disabling disorders. The vast majority of all pain episodes show recovery in a few weeks without any treatment, but, at the same time, the recurrence rates are high. In epidemiologic studies, it is difficult to define the time of onset of most musculoskeletal disorders and to distinguish between the incidence and recurrence of these disorders. As a consequence, little is known about the crucial time window that relates to an episodic event of the musculoskeletal disorder of interest in the subject's work history. Probably, exposure and disease are dynamically related, whereby, in each disease stage, different sets of risk factors influence the occurrence of the disease (9).

In this article current methods and strategies for the assessment of work-related risk factors for musculoskeletal disorders are presented, primarily illustrated by assessment strategies for physical load in epidemiologic studies on back disorders. The primary goal is to provide the reader with information to improve the

assessment of work-related risk factors in musculoskeletal epidemiology.

Assessment of exposure

Assessment techniques for exposure to risk factors in musculoskeletal epidemiology can be broadly classified into the following 3 categories of data collection: (i) subjective judgments, (ii) systematic observations, and (iii) direct measurements. Exposure measures should be selected that permit specific etiologic inferences. In addition, exposure should be expressed by all of its 3 principal dimensions, level, duration, and frequency.

With regard to individual and psychological risk factors, in epidemiologic studies, information is commonly gathered from the worker's response to questions in self-administered questionnaires, diaries, or interviews (9). Self-reports yield information that is subject to systematic bias and lack of precision. Little is known about the factors that may affect a worker's self-reports, such as the interrelationships between work-related risk factors and the worker's health status. However, in a recent study, no support was found for differential bias in exposure ratings in studies on musculoskeletal disorders in which subjects reported both exposure and outcome variables (10). Other assessment techniques are not often used for psychological factors, but some epidemiologic studies have managed to include objective measures of psychological load, for example, by measuring catecholamines in urine as a proxy for stress experienced by truck drivers (11).

In recent years several different methods have been developed to assess physical load at the workplace. These methods partly differ from the well-established techniques used in laboratory experiments (12). Self-reports by means of questionnaires or diaries offer the possibility to investigate many subjects at a reasonable cost. Clear disadvantages are the limited precision for most estimates of exposure and their moderate reliability when expressed on an ordinal scale (12, 13). Hence the application of a worker's self-reports or expert judgments is restricted to the assessment of physical load in occupational groups in qualitative classifications, like low, moderate, and high.

Observational methods and direct measurement techniques are increasingly being used. Observing workers is time consuming, but direct measurements are often accompanied by high costs for equipment and time for calibration and analysis. Direct observations on the spot are very effective when awkward postures and manual materials handling are simultaneously assessed in dynamic work situations and, hence, have certainly a place in

epidemiologic studies on musculoskeletal disorders (13, 14). Direct measurement techniques vary from inclinometers to record postures and movements, force gauges to measure exerted forces, to electromyographic registration devices to assess muscle activity. Direct measurements are focused on specific components of physical load and, thereby, have to be integrated with other measurements. The trade-off is the abundant detail on level, duration, and frequency of the parameter of interest.

In general, direct measurement techniques are favored for their precise and accurate measurements, as well as for their informational content (12, 15). For epidemiologic purposes, the direct registration of exposure data as a function of time prompts for analytic methods which reduce the available amount of data into a limited number of essential parameters but still sufficiently capture the exposure patterns. Mathiassen & Winkel (15) have proposed an exposure variation analysis whereby exposure level, duration, and frequency are summarized in a data matrix. Table 1 presents an application of this method in an ongoing study on patterns of posture and movement among workers in Dutch nursing homes. An inclinometer was attached to the trunk at the L2-L3 level, and for 8 hours the angular position of the trunk in the sagittal plane was continuously recorded with a frequency of 16 Hz. Altogether 38 nurses and 19 office workers were measured during a regular workday. The exposure level (trunk angle) was divided into 4 classes, and the exposure duration (duration of trunk posture in a particular angular class) was broken into 5 classes. The exposure frequency (number of times the trunk moves from an angular class of 20 degrees to another), as well as the percentage of trunk postures in a particular angle for a particular time, are presented in each cell of the matrix. The data clearly demonstrate the nature of the work activities among nurses in comparison with that of the office

workers. The nurses more often flexed their trunk over 40 degrees (104 per hour versus 48) and 60 degrees (46 versus 19) and spent more worktime in these postures (5.0% versus 2.4% and 1.9% versus 1.0%, respectively). This matrix analysis also illustrates that the often-adopted measure of exposure of percentage worktime with 20 degrees of flexion does not discriminate between groups, whereas larger angular flexion shows clear differences.

Design of a measurement strategy

The choice for a particular measurement device not only depends on the features of the technique, but also on its feasibility in an epidemiologic study, the level of detail required in the exposure assessment, and the variation in exposure distributions within and between workers. A workplace survey for assessing risk factors for musculoskeletal disorders will attempt to collect a sufficient amount of data to describe exposure patterns in the study population. In the case of physical load, given its considerable variability in time, the best approach would be to obtain information for each worker on his or her exposure distribution over a period of several weeks, during which measurements are taken during a series of tasks and in workplaces representative to their jobs. Such an ideal is very difficult to achieve in practice. Therefore, one solution is to collect representative samples from workers or situations with similar exposure patterns and, subsequently, extrapolate to workers and situations not monitored. Thus decisions must be made about how best to allocate the measurements, taking into account the performance of measurement instruments, the aims of the survey, the variation in ergonomic stressors, and cost

Table 1. Average frequency of trunk flexion in angular classes per hour, stratified by duration of trunk flexion, during a regular workday among nurses (N=38) and office workers (N=19) in a nursing home.

	Trunk flexion							
	<20 degrees		20—<40 degrees		40—<60 degrees		≥60 degrees	
	Number of subjects	%	Number of subjects	%	Number of subjects	%	Number of subjects	%
Nurses								
0—<1 seconds	141	20.3	115	16.6	58	8.4	26	3.7
1—<5 seconds	84	12.1	115	16.6	42	6.1	18	2.6
5—<10 seconds	6.9	1.0	27	3.9	3.0	0.4	1.3	0.2
10—<30 seconds	3.3	0.5	29	4.1	1.2	0.2	0.5	0.1
≥30 seconds	0.8	0.1	21	3.0	0.2	0.0	0.1	0.0
Office workers								
0—<1 seconds	156	25.9	143	23.9	26	4.3	11	1.7
1—<5 seconds	75	12.5	90	15.0	19	3.1	6.9	1.1
5—<10 seconds	8.6	1.4	17	2.8	1.6	0.3	0.6	0.1
10—<30 seconds	7.5	1.2	19	3.1	1.2	0.2	0.4	0.1
≥30 seconds	2.9	0.5	16	2.6	0.4	0.1	0.0	0.0

Table 2. Basic considerations in establishing a measurement strategy for work-related risk factors for musculoskeletal disorders.

Feature	Consideration
Exposure measure	Etiologic relevance (posture, force, trunk muscle activity)
Exposure dimension	Level, duration, frequency
Technique or device	Accuracy and precision (precision versus repeated measurements), feasibility and costs
Subjects	Group approach versus individual assessment, number of subjects
Workplace conditions	Sampling procedure for workplace and work conditions
Temporal variation	Frequency and duration of measurements, number of measurements versus number of subjects

considerations (14). The core considerations for the design of a measurement strategy are summarized in table 2.

In table 3 the comparison of 2 measurement methods for trunk flexion illustrates common problems in assessment strategies. In a nursing home, trunk flexion among 3 groups was studied by means of direct observation over 2 hours (360 observations per worker) and direct registration using an inclinometer with a sampling frequency of 16 Hz over 8 hours (approximately 460 000 data points). Both techniques were applied on the same day for any given worker in the study population. First, large standard deviations were obtained with both measurement techniques, which indicate substantial variation in trunk flexion within and between workers. Second, the average percentage of worktime with trunk flexion over 45 degrees in each occupational group was similar for both measurement techniques, but a cut-off point at 20 degrees flexion showed significant differences that may be explained by differences in accuracy and precision, as well as by the different definitions of trunk flexion used in the methods (11). Third, the correlation (r) between the estimate based on 2 hours of observation and the 8 hours of inclinometer measurements was low for the office workers ($r = 0.24$) and the maintenance workers ($r = 0.25$), and totally absent for the nurses ($r = -0.06$). These low correlations point at the importance of time-dependent variation in exposure since the observational method has a more than a 1000-fold lower number of samples.

A commonly adopted approach in epidemiologic surveys on musculoskeletal disorders is to monitor a random sample of workers in each occupational group of

interest and, consequently, to use the average exposures to describe the physical load of all workers within the occupational groups. Workers are assigned a priori to an exposure group that is supposed to encompass all workers with a similar exposure profile (homogeneity) and that is still distinguishable from other occupational groups (contrast). A bootstrapping technique can be applied to evaluate the minimum number of workers required to arrive at a precise estimate of the average exposure (16). For the assessment of trunk flexion with direct observations it has been shown that the best strategy is to select occupational groups with ample contrast in average exposure rather than strongly homogeneous exposure groups, to rank occupational groups in 3 to 5 distinguishable levels of exposure, and to focus on valid estimates of the group's average exposure by monitoring a random sample of 15 to 25 workers within each occupational group (16). It should be mentioned that these recommendations can differ for other work-related risk factors and that occupational groups may differ substantially from each other. Ideally, for each job title and for each exposure variable, a pilot survey should be conducted to determine the optimum measurement strategy. Of course, there is a trade-off in the effort researchers should put into such pilot studies when compared with the main study itself. Many musculoskeletal epidemiologic studies, however, remain far from evaluating the best feasible measurement strategy.

A measurement strategy at the individual level will require a substantially larger effort. For valid assessments of a worker's average physical load, this worker has to be monitored repeatedly or, alternatively, monitored with increasing averaging time of measurement. The appropriate number of measurements per subject or the optimum measurement duration is relative to the load variation of the workers under study and the reliability of the measurement technique applied. Statistical techniques are available to evaluate various design options in assessment strategies in relation to the precision needed (13). These formulas can be applied to discuss the choices between number of measurements versus number of subjects and between the precision of the method and the number of measurements. It can be shown that an individual assessment with a specified degree of reliability (eg, reliability coefficient of 0.8) for the duration of sitting with a

Table 3. Percentage of worktime with trunk flexion over 45 degrees as assessed with an inclinometer (8 hours) and by direct observation (2 hours).

Group	Inclinometer			Direct observation		Correlation
	N	Mean	SD	Mean	SD	
Office workers	18	1.0	1.0	0.8	0.9	0.24
Maintenance workers	18	2.3	2.0	2.5	2.9	0.25
Nurses	18	3.9	2.2	3.7	3.0	-0.06

questionnaire requires 16 repeated measurements in work situations with a ratio of within-worker to between-worker variability of 4 as obtained by this questionnaire.

Development of exposure metrics in epidemiology

In musculoskeletal epidemiology the exposure assessment strategy encompasses several work-related risk factors. When appropriate strategies are being designed, the following 2 interrelated issues have to be addressed: the selection of variables that permit specific etiologic inferences and their parameterization. Researchers are usually faced with a large array of variables that need to be quantified. In general, this quantification requires a comprehensive measurement effort that combines different approaches and measurement techniques into a limited number of exposure measures that should adequately describe exposure profiles in the populations under study.

Some authors have argued for a common metric that converts inputs from disparate measurement methods into estimates of exposure in the same units. The rationale is that this strategy greatly facilitates data reduction and that it may present a consistent measure for exposure across different jobs (8, 17). In a recent questionnaire study, workers were asked to rate their exposure on a Borg CR-10 scale for 8 different risk factors, including exposure to nonneutral postures, work pace, vibration, manual forces to handle tools, and mechanical pressures from handheld tools in the worker's usual job (18). The overall exposure score was categorized into 4 levels, and significant dose-response trends were observed for disorders of the upper extremities, shoulders, and wrists or hands. This strategy may contribute to the epidemiologic verification of existing ergonomic guidelines since most guidelines are based upon psychophysical studies using subjective ratings as end points in highly controlled laboratory experiments. A second strategy to develop a common metric has been proposed by Moore and his colleagues in their analysis of jobs at risk of distal upper-extremity disorders in the pork-processing industry (19). They introduced a so-called strain index as a product of 6 scores for intensity, duration, and frequency of exertion, wrist posture, speed of work, and duration of tasks per day. The rating scheme used quantitative cut-off points, and the exposure assessment was based on actual measurements at the workplace and expert judgment. A clear dose-response relationship was observed between the strain index and the incidence rate of disorders of muscle-tendon units in the upper extremities (19).

Both examples of common exposure metrics weigh different exposure dimensions on a similar scale. For etiologic studies this certainly is a disadvantage since the relative contribution of the different risk factors includ-

ed in the common metric cannot be determined. An alternative approach is to limit the common exposure metric to the risk factors that can be measured in the same unit. For example, biomechanical linked-segment models can be combined with external exposure data (posture, movement, and exerted force) and anthropometric details in order to estimate compression and shear forces at the lumbosacral joint. Hence, the resulting measure (in Newtons) is used as a proxy for the internal exposure to forces acting on a particular part of the spine. In a recent case-referent study, it was demonstrated that several parameters of cumulative physical loading of the spine were significantly increased among workers with low-back pain when they were compared with those without low-back pain (20).

The common exposure metric allows a flexible approach with which to select measurement methods as long as their results can be translated into the metric of interest. A drawback of this approach is that the measurement strategy is less tailored to the quantification of the determinants of the variability of exposure. An alternative approach is the modeling of the original exposure measures with the aim of accounting for temporal patterns of risk factors in the analysis. A recent study illustrated that exposure assessment at the individual level was substantially improved by linking task-based estimates of physical load (direct observations) with individual task registration (self-reports in a log) (21). The modeling of exposure greatly reduced the random measurement error but still presented detailed information on the physical load of each worker. The modeled worktime with forceful exertions over 100 N was significantly associated with the occurrence of elbow pain and wrist pain, whereas the estimates of worktime with forceful exertions, derived directly from the observations, showed no association at all. This strategy may be especially successful in workplaces with highly dynamic work.

A related topic still largely unaddressed is the critical time window of risk factors for musculoskeletal disorders. For example, the interval between the lifting of a heavy load and the development of low-back pain is short for some cases, whereas most cases of low-back pain appear to develop after a number of years of moderate-to-heavy lifting. Although seldom applied in musculoskeletal epidemiology, the case-crossover design is an innovative study design with which to evaluate the impact of transient exposure on the risk of acute onset events (22). Studies on the relevant time window for musculoskeletal disorders may require a hybrid design, combining a case-crossover with a cohort design. In general, studies aimed at addressing the latency period for a particular musculoskeletal disorder are complex in that detailed assessment of temporal variation in exposure is required, as is an appropriate characterization of distinguishable episodes of the disorder of interest.

Concluding remarks

This paper reviews some of the challenges in exposure assessment posed to researchers in musculoskeletal epidemiology. A variety of design options is available, each with its own strengths and weaknesses. There is a clear trend towards the quantification of work-related risk factors through direct measurements. In any measurement strategy the most challenging problem is the optimal utilization of available resources in relation to the study design, the risk factors of interest, and the sources of variation in exposure to these risk factors within and between workers.

References

1. Bernard BP. Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremities, and low back. Cincinnati (OH): National Institute for Occupational Safety and Health, 1997.
2. Hagberg M, Silverstein B, Wells R, Smith MJ, Hendrick HW, Carayon P, et al. Work related musculoskeletal disorders (WMSDs): a reference book for prevention. London: Taylor & Francis, 1995.
3. Riihimäki H. Low-back pain, its origin and risk indicators [review]. *Scand J Work Environ Health* 1991;17:81—90.
4. Burdorf A, Sorock G. Positive and negative evidence of risk factors for back disorders [review]. *Scand J Work Environ Health* 1997;23:243—56.
5. Mital A, Nicholson AS, Ayoub MM. A guide to manual materials handling. London: Taylor & Francis, 1993.
6. Waters TR, Putz-Anderson V, Garg A, Fine LJ. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics* 1993;36:749—76.
7. Dempsey PG. A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. *Ergonomics* 1998;41:73—88.
8. Winkel J, Mathiassen SE. Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics* 1994;37:979—88.
9. Burdorf A, Rossignol M, Fathallah F, Snook S, Herrick R. Challenges in assessing risk factors in epidemiologic studies on back disorders. *Am J Ind Med* 1997;32:142—52.
10. Toomingas A, Alfredsson L, Kilbom Å. Possible bias from rating behavior when subjects rate both exposure and outcome. *Scand J Work Environ Health* 1997;23:370—7.
11. Van der Beek AJ, Meijman TF, Frings-Dresen MHW, Kuiper JJ, Kuiper S. Lorry drivers' stress evaluated by catecholamines excreted in urine. *Occup Environ Med* 1995;52:464—9.
12. Van der Beek AJ, Frings-Dresen MHW. Assessment of mechanical exposure in ergonomic epidemiology. *Occup Environ Med* 1998;55:291—9.
13. Burdorf A. Reducing random measurement error in assessing postural load on the back in epidemiologic surveys. *Scand J Work Environ Health* 1995;21:15—23.
14. Kilbom Å. Assessment of physical exposure in relation to work-related musculoskeletal disorders — what information can be obtained from systematic observations? *Scand J Work Environ Health* 1994;20 special issue:30—45.
15. Mathiassen SE, Winkel J. Quantifying variation in physical load using exposure-vs-time data. *Ergonomics* 1991;34:1455—68.
16. Burdorf A, Van Riel M. Design of strategies to assess lumbar posture during work. *Int J Ind Ergon* 1996;18:239—49.
17. Wells R, Norman R, Neumann P, Andrews D, Frank J, Shannon H, et al. Assessment of physical work load in epidemiological studies: common measurement metrics for exposure assessment. *Ergonomics* 1997;40:51—61.
18. Punnett L. Ergonomic stressors and upper extremity disorders in vehicle manufacturing: cross-sectional exposure-response trends. *Occup Environ Med* 1998;55:414—20.
19. Moore JS, Garg A. The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. *Am Ind Hyg Assoc J* 1995;56:443—58.
20. Norman R, Wells R, Neumann P, Frank J, Shannon H, Kerr M. A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clin Biomech* 1998;13:561—73.
21. Burdorf A, Van Riel M, Brand T. Physical load as risk factor for musculoskeletal disorders among tank terminal workers. *Am Ind Hyg Assoc J* 1997;58:489—97.
22. Mittleman MA, Maldonado G, Gerberich SG, Smith GS, Sorock GS. Alternative approaches to analytical designs in occupational injury epidemiology. *Am J Ind Med* 1997;32:129—41.