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Design of strategies to assess lumbar posture during work

Alex Burdorf [a,b,*], Marcel van Riel [c]

[a] *Department of Public Health, Erasmus University, P.O. Box 1738, NL-3000 DR Rotterdam, The Netherlands*
[b] *Department of Epidemiology and Public Health, Wageningen University, Wageningen, The Netherlands*
[c] *Department of Biomedical Physics and Technology, Erasmus University, Rotterdam, The Netherlands*

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Abstract

Quantitative characterization of postural load on the back should describe exposure patterns among workers and factors affecting these exposure patterns. This article presents general guidelines for designing appropriate measurement strategies; how to obtain detailed data with an applicable measurement method, what sampling strategy should be applied, which frequency and duration of measurements are required, and how differences between workers, shifts and tasks are addressed. Formulae are available to evaluate the best trade-off between the reliability of a measurement device and repeated measurements and between the number of workers to be monitored and the number of measurements per worker. More difficult questions relate to collective assessments versus individual assessments and duration versus frequency of measurements. Methods are described for statistical modelling of data on trunk flexion and rotation. A two-way analysis of variance was applied to assess the principal sources of variation in back load among workers in the woodworking industry. A bootstrapping technique was used to evaluate the minimum number of measurements required to arrive at an unbiased estimate of the average exposure to trunk flexion in two occupational groups. It is advisable to conduct a small pilot study to determine the essential features of the measurement strategy before undertaking a large study comprising many workers and many work situations.

Relevance to industry

In order to reduce the occurrence of work-related musculoskeletal disorders in occupational populations, quantitative assessment of work-related risk factors is needed. This article presents a framework for the design of exposure assessment strategies, using physical load due to trunk posture as an example. General guidelines are presented to accommodate optimal measurement of physical load at work.

Keywords: Postural load; Assessment; Measurement

1. Introduction

Low-back pain constitutes a major health problem in many occupational populations. Occupational factors frequently mentioned as risk factors for low-back pain are heavy physical work, static work postures, frequent bending and twisting, lifting and forceful movements, and whole-body vibration (Andersson,

* Correspondence author. Tel.: +31 10 408 7714; Fax: +31 10 436 6831.

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1981; Riihimäki, 1991). Apart from the latter, all other occupational risk factors have a common biomechanical thread; mechanical load on the lumbar spine is considered to be of causative importance to disorders of the back, including low-back pain (Chaffin and Andersson, 1991).

Despite this evidence associating low-back pain with a variety of work activities and risk factors, dose–response relationships between mechanical load at work and low-back pain are far from clear. The lack of quantitative data on these relationships may be explained, to a large extent, by poor exposure assessment (Winkel and Mathiassen, 1994). In epidemiologic studies, occupational risk factors are usually determined at a qualitative level that is often too crude to arrive at reliable assessments of an individual's exposure (Burdorf, 1992a). Similar problems are encountered in ergonomic workplace surveys aimed at identifying mechanical load among workers and evaluating the implications of job and task demands for the adoption and variation of work postures. Traditional approaches determine the maximum back load of a typical worker performing a stereotype action, but the contribution of this action to the total load experienced by each worker over a work day is seldom assessed. Hence, not surprisingly, there are few quantitative criteria to define work postures appropriate for the task being performed and durations allowed to maintain specific postures in a particular work environment (Haslegrave, 1994).

In order to study dose–response relationships between mechanical load and low-back pain and to institute effective ergonomic improvements, attention is needed towards quantitative characterization of mechanical load describing exposure patterns and factors affecting these exposure patterns. Currently, assessments of mechanical load by observational and direct methods are often restrained to a short period for a selected group of subjects, typically covering a few complete work cycles or time spans up to 1 h during a normal work day. It should be questioned whether such a strategy presents valid exposure assessments for the subjects under study and whether the exposure pattern is representative for workers in the same job (Burdorf, 1992a; Winkel and Westgaard, 1992). Whilst the basic work activity may remain the same over time, there are many other factors operating which can cause considerable variation in mechanical back load among workers in a specific job. The extent and significance of these factors are still largely unchallenged in strategies to assess mechanical back load at the workplace.

This article reviews the existing literature on considerations in the design of an appropriate exposure assessment strategy, on exposure variability in exposure estimates, and on sampling procedures on subjects and measurement periods. The review is restricted to exposure assessment at the workplace during routine work activities; characterization of exposure during laboratory experiments and simulated work tasks have their own merits. The assessment of back load due to trunk posture is taken as an example, but many considerations also hold true for other measures of mechanical load. The purpose of this paper is to describe terminology and methods regarding assessment of postural load on the lumbar spine, to discuss various options in designing of measurement strategies, and to provide some examples of their application. General guidelines are presented as to quantitative assessment of postural load on the back in occupational populations.

2. Exposure assessment

2.1. Basic considerations

Exposure usually refers to the presence of an agent or factor in the environment external to the worker (Armstrong et al., 1993). In ergonomics, rigidly applied, this would restrict exposure to external factors such as workplace design, size and shape of objects, work pace, and work tasks to be performed. However, without workers adopting specific postures, there would be no exposure at all. In the case of back disorders, exposure can be considered as the external load forced upon the worker by the physical work requirements; the worker adopts specific postures, executes movements, and exerts forces. Since individuals usually adapt a personal work style, the external load depends on the workplace characteristics and work demands as well as the worker's ability to apply particular work techniques. In this respect, exposure to ergonomic stressors essentially differs from other hazardous working conditions.

When restricting external load on the back to non-neutral trunk postures, assessment of lumbar posture is performed for many reasons, such as identification of strenuous tasks and activities in particular jobs (Malchaire and Rekz-Kallah, 1991), surveillance for ergonomic hazards at work (Harber et al., 1992), characterization of exposure in epidemiologic studies (Winkel and Mathiassen, 1994; Punnett et al., 1991), and evaluation of the effectiveness of ergonomic controls (Hultman et al., 1984; Burdorf and Van Duuren, 1993). These assessments have in common that they purport to make available information that allows inferences on the exposure distribution for a group of workers. Whatever exposure information is to established, in every measurement strategy, several basic issues have to be addressed. Table 1 summarizes the 5 elements fundamental to a measurement strategy. Consideration of these factors in relation to the particular aim of the workplace survey can lead to a wide range of approaches that cannot be covered exhaustively in this article. However, the principles of applying the basic elements remain similar throughout various measurement strategies.

2.2. Parameters and measures of exposure

The first step in assessment of lumbar posture at work is to consider the appropriate parameters and measures of exposure. The characterization of exposure should relate to the health effect of interest and express the 3 essential measures of any exposure parameter: level, duration, and frequency. In most surveys, the principal parameter of exposure is the angular position of the trunk, usually expressed on a categorical scale, even when real-time registration of angular trunk position took place. A popular standard is the division into various regions representing neutral, mild, and severe flexion, lateral bending or rotation (Genaidy et al., 1994; Keyserling et al., 1993). Marras et al. (1993) also focused on other exposure parameters, demonstrating that average twisting velocity (deg/s) as well as maximum sagittal flexion (degrees) and maximum lateral velocity (deg/s) were important factors to distinguish between high-risk and low-risk jobs for back injuries among workplaces involved with repetitive manual handling work. Thus, in most work situations, emphasis is given to the level of exposure. The frequency of exposure parameters, that is, changes from one exposure level to another, is seldom presented in surveys on back load although this measure may hold important information on the repetitive nature of the work (Mathiassen and Winkel, 1991).

Duration of exposure is usually combined with exposure level to a time-weighted average, for example 10% work time with trunk flexion over 20°. Since chronic damage is likely to be proportional to the cumulative exposure, the daily time spent in non-neutral trunk postures is often used as a proxy for cumulative exposure. This approach was used in a case-referent study among automobile assembly workers that showed that back disorders were strongly associated with mild trunk flexion (21–45°),

Table 1
Basic considerations in establishing a measurement strategy for postural load on the back among occupational populations

Feature	Consideration
Parameter and measure	Characterization of the parameter and measure of exposure relevant to the health effect
Measurement technique	Accuracy and precision of the technique in exposure conditions to be expected as well as feasibility of the technique under different circumstances
Subjects	Which workers should be studied, how are these workers selected, and how many workers should be monitored
Workplace conditions to be included	Sampling procedure for workplaces and working
Temporal variation	Procedure to determine frequency and duration of the periods that should be monitored to obtain valid assessments of workers' exposure distributions

severe trunk flexion (> 45°), and trunk twist or lateral bend (> 20°) (Punnett et al., 1991).

2.3. Measurement technique

The choice of a particular measurement technique depends on the level of accuracy and precision required in relation to the objective of the survey. To identify work activities with high back load a semi-quantitative technique with only moderate accuracy and precision is sufficient, such as the Finnish OWAS system (Matilla et al., 1993) and the German AET system (Rohmert, 1985). Direct observational methods used by trained observers have shown reliability coefficients of over 0.60 (Genaidy et al., 1994; Burdorf, 1995). In the case of ergonomic analysis of a workstation layout by means of biomechanical modelling, instantaneous observations at the workplace do not provide the level of high precision required. In this type of study, it may be necessary to produce detailed, real-time measurements of trunk movements by (video) recording of all work sequences in the job (Keyserling and Budnick, 1987). Available devices are usually very precise with measurement errors often below 2–3°.

When establishing exposure–response relationships for back disorders, assessment of back load should be able to discriminate between estimates of individual workers. Direct observation techniques may meet this requirement when a limited number of exposure parameters are recorded simultaneously (Burdorf, 1995). Video techniques and direct instrumentation are to be preferred when modelling of exposure parameters is an essential part of the study. However, feasibility considerations may argue for the use of observers at the workplace because sophisticated measurement devices, such as three-dimensional video-techniques, are extremely labour intensive and their applicability is limited to stationary jobs with repetitive movements (Aarås and Stranden, 1988). It should be noted that, in general, the measurement technique should fit the requirement of the measurement strategy and not vice versa.

2.4. Subjects and workplaces

There are no simple universal rules as to choose which workers and work conditions to monitor. A few studies have demonstrated a substantial range in posture among workers performing identical tasks (Kilbom and Persson, 1987; Burdorf, 1992b; Harber et al., 1992). Thus, in a workplace involving few workers it may be sensible to sample them all. In large populations workers are usually assigned to groups with similar exposure patterns and, subsequently, workers representative of each exposure group are monitored. It is recommended to examine whether the assumption of uniformly exposed workers in distinguished groups holds true. When the assignment of workers to various exposure groups makes sense, the rank ordering of the group's mean exposure to back load will reveal the importance of workplace factors for the distribution of back load among the population under study.

2.5. Temporal variation

The last feature of a measurement strategy is the temporal variation of postural load on the back. Only a few studies have addressed this problem since it requires repeated measurements on the same workers. In a study among supermarket checkers, 50 workers were videotaped for about 10 replications of checking particular items. It was shown that there was considerable variability in back load within subjects over time; using a scale from zero to two to assess the extent of lumbar flexion, the standard deviation exceeded the arithmetic mean during handling of various typical supermarket items (Harber et al., 1992). When replicate observations during 30-min periods on the same day were made of workers in 5 different occupations, the assessments of the exposure measure 'percentage work time with trunk flexion over 20°' varied 3-fold within individual packers in a flower auction up to 36-fold within individual operators of woodcutting machines in various small enterprises (Burdorf, 1992b). A third study among workers involved in manual materials handling described that less than half of the variation in trunk motions was attributable to temporal variation and/or differences among workers (Marras et al., 1993).

The implications of these temporal variations are difficult to evaluate since the variation due to instrumental characteristics (precision, averaging time) was not disentangled from true temporal variation in lumbar posture. It is possible to calculate the coefficient of variation in the measurement technique by performing intramethod/intermethod reliability surveys. Subsequently, the distribution of postural load among workers can be corrected for the variation in exposure due to instrumental characteristics. In a study using an observational technique, it was shown that an inter-observer agreement of 80% explained less than 6% of the variation in trunk flexion and rotation among workers in the same occupational group (Burdorf, 1992b).

3. Design options in measurement strategies

3.1. Necessary choices

A workplace survey for assessing postural load on the back will attempt to collect a sufficient amount of data to describe exposure patterns in the study population. Ideally therefore, the best approach would be to obtain information for each worker on his exposure distribution of back load over a period of several weeks, where measurements are taken during a series of tasks and workplaces representative of their job. Such an ideal is very difficult to achieve in practice. Therefore, a measurement strategy aims at reducing the number of samples required, and yet measure sufficiently to arrive at sound conclusions. The only way to reduce the measurement program 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 to best allocate the available number of measurements in order to collect sufficient data to describe exposure patterns. Five crucial choices will be discussed in more detail in the next section.

Cost considerations are not dealt with in this section, but the choices to be made may be evaluated economically in order to obtain the most cost-effective study design.

3.2. Stratified analysis versus random approach

Surveys are always carried out to obtain unbiased estimates of an individual's 'true' exposure, whether by assessing back load of each individual separately or by obtaining an estimate of the mean back load in the group that is supposed to apply to each individual in that group. A random sample of subjects and periods to be monitored may be drawn or, alternatively, the population is divided into various strata and a random sample is drawn independently in each stratum. Stratification will significantly reduce the measurement effort compared with the random approach by sampling proportional to the number of subjects and the variation in back load within each stratum (Snedecor and Cochran, 1989). Familiar stratification criteria are job title, shifts, tasks performed, machinery and equipment used, and materials handled. Other factors that may also introduce systematic differences, such as work techniques adopted and anthropometric characteristics, are more difficult to stratify for, and will result in (seemingly) random variation.

In epidemiologic studies on back disorders, assessment of postural load is often stratified by job title. However, large variation within occupational title groups dilutes the contrast in exposure between these groups and, hence, it may be impossible to apply job titles as classification criterion for postural load (Burdorf, 1992b). It has been suggested that individual assessments can be arrived at by assessing the distribution of tasks among individuals as well as physical load within separate tasks (Winkel and Mathiassen, 1994). Such an approach will be particularly fruitful in surveillance surveys on a limited number of tasks that dominate the exposure patterns (Grieco et al., 1989; Harber et al., 1992). However, in epidemiologic surveys, it may be too difficult to obtain for every individual reliable data on the time spent in each task.

Since individual differences in work practices appear to be important in most occupations, within-task sampling is unlikely to be satisfactory unless it can be shown that individuals perform tasks in a similar manner with regard to back load. A randomized measurement strategy might be favoured for jobs involving intermingling tasks that make characterization of tasks difficult and quantification of task components almost not feasible. As a means of collecting exposure estimates both on subjects and tasks, methods have been applied that record trunk postures during work while simultaneously observing the tasks performed. Results were used to assess postural load among the subjects under study, to describe postural load during specific activities, and to target tasks for more detailed analysis or for ergonomic improvements (Harber et al., 1987). It is obvious that this approach is most suitable for tasks frequently performed since an infrequent task might not be encountered unless a worker is monitored over several days.

3.3. Collective assessments versus individual assessments

A basic question in ergonomic surveys is: "Do we have to measure all workers?". In many surveys it will suffice to classify workers into broad exposure groups that discriminate between low, intermediate, and high load. This approach might be quite powerful, even with limited data, when the estimate of the average exposure in each exposure group is relatively precise in relation to the contrast in exposure between the groups. This requires grouping of workers into exposure groups that are sufficiently homogeneous and a measurement strategy that allows for precise assessment of the mean postural load in distinguished groups. Heterogeneity in exposure groups will introduce (random) bias in established dose–response relationships between back load and back disorders. In the section on statistical modelling, a simulation approach on existing data is presented that can be used to evaluate the appropriate number of measurements needed that result in a precise estimate of the average exposure to back load among a group of workers.

The efficiency of a measurement strategy depends on minimizing the between-worker variation within the exposure groups, maximizing the between-group variation, and maximizing the precision of the exposure estimates within the groups (Armstrong et al., 1992). When the between-worker variation is large, it may be virtually impossible to assign workers to exposure groups since each worker may end up in its own exposure group. In these situations individual assessment of back load can be inevitable and, thus, a sharp increase in the number of measurements is required.

3.4. Method precision versus repeated measurements

The precision of a measure of exposure refers to its repeatability and reproducibility. Under specific assumptions (e.g., high accuracy), the precision of a measurement instrument can be expressed by the reliability coefficient, obtained by applying this measurement method to the same workers at two points in time. This reliability coefficient includes the random measurement error due to instrumental features (performance of the measurement method) as well as the exposure variation within and between workers, assuming that the latter variation also is random. The underlying theory is that the precision of the estimate of the average exposure of a worker increases with larger number of measurements per subject.

Thus, the moderate reliability of a measurement method can be counterbalanced by repeated measurements. Formula are available to calculate the number of repeats necessary to achieve a specified degree of reliability (Armstrong et al., 1992). For example, with equal within-worker and between-worker variance, the reliability coefficient will increase from 0.50 to 0.77 when monitoring workers 3 times instead of once. A strategy with repeated measurements may open the way to application of instruments with a moderate precision, such as direct observation methods (Burdorf, 1995).

3.5. Number of measurements versus number of subjects

The usual design approach is to determine the number of workers needed to differentiate between two levels of exposure; for example, by using straightforward formula based on the t-statistics. On the analogy of the previous consideration, an alternative approach involves recruitment of a smaller number of workers so that each worker can be monitored on more than one occasion. Formulae have been described to calculate the number of subjects in relation to the number of repeated measurements for each subject (Burdorf, 1995). These formulae combine the classical equations for determining the power of a study and the expressions for evaluating the influence of exposure variation on the reliability coefficient of the average exposure. The efficiency of increasing the number of repeated measurements or, vice versa, increasing the sample size, is determined by the ratio of within-worker to between-worker variation and the study costs.

3.6. Duration versus frequency

This consideration is quite similar to the previous one. It is obvious that as the averaging time of the measurements increases, the temporal variation will be smoothed. Longer duration of the measurements will increase the precision of the estimated mean, but the arithmetic mean itself is constant and independent of the averaging time. Therefore, in a monotonous job with a relative high level of repetition, recording of trunk postures during a few work cycles can be sufficient to assess individual exposure in the job. In contrast, in a highly dynamic work environment, much longer measurements may be needed to arrive at estimates of the 'true' back load. Alternatively, the frequency of measurements may be increased since precision can also be improved with the greater the number of samples taken. There are no general guidelines available to evaluate the best trade-off between repeated and prolonged measurements. Computer simulations on detailed quantitative exposure distributions have to be performed to explore the effect of frequency and duration of measurements on estimation of the average exposure of individuals.

4. Statistical modelling of exposure

Statistical evaluation of exposure data is a helpful tool in understanding why back load varies among workers and in unravelling the primary factors affecting the worker's exposure to back load. Statistical evaluation may take various models for analysing the data; this section will only demonstrate two versatile applications that offer practical benefits in designing measurement strategies.

All data are derived from studies on trunk posture in the sagittal plane (flexion > 20°) and the transversal plane (rotation > 20°) among occupational groups. The method of measurement used was the Ovako working posture analysis system (Matilla et al., 1993) which was slightly modified to separate flexion and rotation during observation. In every survey, workers were observed every 20 s during a period of 30 min, thus collecting 90 observations per worker per measurement. Each worker was observed twice on the same day; the first period was randomly chosen in the first hours of the shift, the second period approximately 4 h later in the same shift. The exposure measure derived is the percentage of the work time spent with the trunk in flexion or rotation. To avoid inter-observer variability, all observations in an occupational group were performed by one person.

4.1. Assessment of time-dependent variation

This survey took place in the filling department of a dairy factory and comprised 28 male operators. During the best part of their shift (72% of work time), these workers were involved in control activities which included small technical adjustments of the machinery. An additional task (15%) was to supply the machinery with feedstock. Minor tasks (13%) included additional lifting actions and rest periods during work. All workers were measured twice on the same day during a 3-week period. After about 2 months, the total measurement program was repeated. A full description of this survey was published elsewhere (Burdorf et al., 1994).

The design of the study was aimed at examining temporal variation between days, within shifts and between workers by means of a two-way nested analysis of variance (ANOVA). In this hierarchic classification, a population is sampled a number of times (the 28 workers) on two separate days (the shifts) and two measurements are taken on each worker per day (the parts within a shift). The mean squares of the ANOVA model and error produced by this analysis were used to estimate the variance components between workers, between days within a worker, and between parts of a shift within a day. The worker's average exposures to trunk flexion and rotation were normally distributed and, thus, arithmetic means (AM) and standard deviations (S.D.) were calculated. The variance components are presented by the standard deviation.

A total of 10 080 observations was collected during 112 measurements, covering 4 periods of 30 min among 28 operators. On average, the percentage of work time spent with trunk flexion was 12.6 (S.D. 6.4) on the first day and 11.4 (S.D. 5.0) on the second day. For trunk rotation the figures were 11.2 (S.D. 5.4) and 5.3 (S.D. 2.4), respectively. In Table 2, the total variability of exposure to trunk flexion

Table 2
Estimated contribution of different sources of variation to the total variability of trunk flexion and trunk rotation among 28 operators in a dairy factory

Source of variance	df	Trunk flexion		Trunk rotation	
		S.D.	%	S.D.	%
Between workers	27	4.1	25.3	0.0	0.0
Between days	28	0.0	0.0	3.9	32.8
Within shifts	56	7.3	74.7	5.8	67.2

df, degrees of freedom; S.D., standard deviation.

and rotation is partitioned into its main components. For both exposure measures the variation within the shift was the largest source of variance with standard deviations of 7.3 for flexion and 5.8 for rotation. The variation of flexion due to day-to-day variation was negligibly small (and omitted in the model) and the between-worker variation accounted for 25% of the total variation. For exposure to trunk rotation, the difference between days was significant and, therefore, contributed significantly to the variation.

This survey demonstrated that the variation within a shift was significant above and beyond the variation between days and among workers. The marginal contribution of the latter source of variation indicates that the current strategy does not allow a specific worker to be singled out; an estimate of the 'true' exposure of individual workers would require more measurements. The insight into the sources of variation may guide the researcher to intervention factors since personal work style seems to be of less importance than work-related factors, such as the distribution of tasks over the shift, and the various machines operated during a shift.

4.2. Sampling with replacement

The previous example of statistical modelling requires quite a large number of measurements in a strict format. In many surveys, a limited amount of data is collected with a small number of workers being monitored only once. The question arises whether the sample was large enough so that the estimate of the average exposure truly reflects the average exposure in the total group of workers. An empirical approach based on sampling with replacement can be employed to evaluate the influence of sample size on the estimate of the average exposure of a group. In bootstrapping, the sample is treated as the population by drawing a large number of 'resamples' of size n from this original sample randomly with replacement. This approach empirically simulates the random component of the average exposure; this technique inductively arrives at an estimate of the 'true' average exposure and its dispersion. The bootstrapping method does not require any assumption on the distribution of the data. This feature is an advantage in studying trunk postures, since the exposure distribution in a group may be highly skewed owing to many workers with moderate values and few persons with high values. For a practical account of this method, the reader is referred to Mooney and Duval (1993).

The bootstrapping technique was used on two populations; the 28 operators in a dairy factory (Burdorf et al., 1994) and 28 operators of planing machines in the woodworking industry (Burdorf and Van Duuren, 1993). The analysis was restricted to the assessments of worker's trunk flexion over the work day. The procedure started with the calculation of the average exposure of 25 workers randomly drawn from both groups. This was repeated 1000 times and the relative frequency distribution of the 1000 averages was used to derive the overall average and the 5th and 95th percentile points of the distribution. The percentile method estimates the 90% confidence interval around the sample's average exposure. Subsequently, the sample size was reduced by one and the whole procedure was repeated until sampling one worker per calculation.

The overall average and the 5th and 95th percentiles are depicted in Fig. 1a and b. For a sample size of 25 dairy operators the average percentage of work time with trunk flexion varied between 10.9% and 14.9%, with an overall average of 12.7% (that is very close to the actual value of 12.6%). For smaller sample sizes, the 90% confidence interval broadens and, thus, the probability of a strongly biased estimator of the average exposure to trunk flexion increases. The confidence interval remained fairly constant after a sample size of about 15 workers. This confidence interval reflects the true variation in trunk flexion between the workers that cannot be reduced by increasing sample size. The bootstrapping procedure among the operators in the woodworking indus-

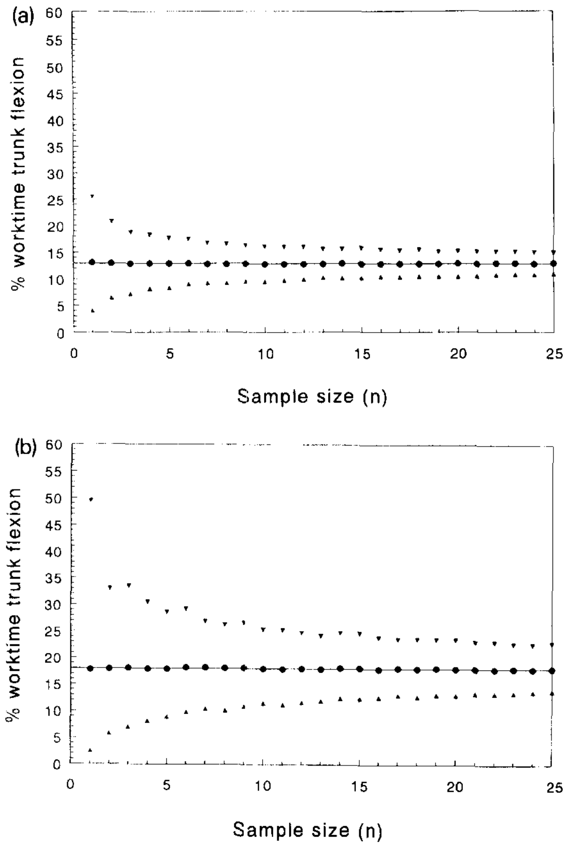

Fig. 1. a: results of bootstrapping of the sample distribution of percentage work time with trunk flexion among 28 operators in a dairy factory. b: results of bootstrapping of the sample distribution of percentage work time with trunk flexion among 28 operators of a 4-sided planing machine in woodworking enterprises.

try showed a somewhat different picture. In this group, the average percentage of work time with trunk flexion was 18.0% with a large standard deviation of 14.1%. Fig. 1b shows that a sample of about 25 workers is needed to be sure that the average exposure of a sample is reasonably close to the true average exposure of the population; the confidence interval ranged from 13.8% to 22.8%. Similar computer simulations were performed for various other occupational groups. For typical values of trunk flexion variation, monitoring between 15 and 25 workers in a group may be adequate to estimate the group average exposure to trunk flexion.

This result may serve as a rule of thumb in strategies for assessment of back load. For example, for an epidemiologic study, the advice may be to choose occupational groups with ample contrast in average exposure rather than selecting homogeneous exposure groups, to rank the occupational groups in 3–5 distinguishable levels of exposure, and to focus on valid estimates of the group's average exposure by monitoring a random sample of 15–25 workers within each occupational group. However, one has to bear in mind that this proposed measurement strategy may need adjustment in work situations with large within-worker and between-worker variation.

5. Discussion and conclusions

Postural load on the back at work has been acknowledged as an important risk factor for developing back disorders in many occupational groups. Quantitative assessment of back load is needed to estimate health risks for individual workers and to institute and evaluate ergonomic improvements at workplaces. Development of appropriate means of measuring and expressing the cumulative load on the back is very important (Winkel and Mathiassen, 1994). Biomechanical models allow assessment of the load on the spine in specific postures and during symmetric lifting tasks. However, these models are predominantly used to quantify peak loads associated with specific actions, but do not incorporate frequency and duration of back load. Interesting attempts have been published that try to link biomechanical modelling to postures and movements during real work situations (Kumar, 1990; Magnusson et al., 1990). Such an approach is becoming increasingly important since biomechanical models can be used to explore the biological relevance of various parameters of back load by putting weights on different exposure periods, exposure patterns, and exposure levels. A few studies have shown the benefits of including various estimates of back load in the analysis of existing relationships between back load and back disorders, since different parameters of exposure may reflect different aspects of back load (Punnett et al., 1991; Marras et al., 1993).

Until now, the area of assessment of back load at the workplace has lagged behind the biomechanical modelling. The essential features of measurement strategies for back load have been seldom discussed, although they 'make or break' the assessments presented. Published material in the scientific literature is difficult to interpret since it often lacks essential characteristics of exposure, such as overall standard deviations of the estimates of the average exposure, frequency and duration of measurements, and principal sources of variation.

When designing a measurement strategy, choices have to be made as to which measurement technique is most suitable, how to sample from exposure distributions, and how to stratify the study population into groups with similar exposure patterns. These features of a measurement strategy are strongly interrelated. The grouping strategy is of paramount importance since any measurement strategy should take into account the profound effect of systematic variation in back load due to tasks, machinery, equipment and materials. Factors that are more difficult to quantify can be characterized by random errors in the estimates of back load, using analysis of variance techniques or reliability surveys. The magnitude of random measurement error should be estimated. Consequently, the optimum allocation of the total number of samples available to the number of subjects monitored, the frequency of measurements and the duration of each individual measurement can be statistically evaluated in relation to the desired precision of the exposure assessments.

To improve the quantitative assessment of postural load on the back in occupational situations, examination of exposure variability is necessary. It seems appropriate to conduct a small pilot survey to determine the essential features of the measurement strategy before undertaking a large study comprising many workers and work situations.

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