Occupational Medicine 2005;**55:**190–199
doi:10.1093/occmed/kqi082

IN-DEPTH REVIEW

Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders

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Background This review provides an overview of the range of methods that have been developed for the assessment of exposure to risk factors for work-related musculoskeletal disorders.

Methods Relevant publications and material on exposure assessment techniques have been gathered for inclusion in this review.

Results The methods have been categorized under three main headings: (1) self-reports from workers can be used to collect data on workplace exposure to both physical and psychosocial factors by using methods that include worker diaries, interviews and questionnaires; (2) observational methods that may be further subdivided between (a) simpler techniques developed for systematically recording workplace exposure that enable an observer to assess and record data on a number of factors using specifically designed pro-forma sheets for establishing priorities for workplace intervention; and (b) advanced techniques developed for the assessment of postural variation for highly dynamic activities that record data either on videotape or are computer analysed using dedicated software; (3) direct measurements using monitoring instruments that rely on sensors attached directly to the subject for the measurement of exposure variables at work.

Conclusions The choice between the methods available will depend upon the application concerned and the objectives of the study. General, observation-based assessments appear to provide the levels of costs, capacity, versatility, generality and exactness best matched to the needs of occupational safety and health practitioners (or those from related professions) who have limited time and resources at their disposal and need a basis for establishing priorities for intervention.

Key words Ergonomics; exposure assessment; measurement; musculoskeletal disorders; observation; review; risk factors; self-reports.

Introduction

In contrast to many occupational diseases that have their origin in exposure to particular hazardous agents, most musculoskeletal disorders (MSDs) are characterized as multifactorial [1]. Findings of scientific research have identified physical [2], psychosocial/organizational [3–5], and individual [6] occupational 'risk factors' for the development of work-related musculoskeletal disorders (WMSDs). These studies have measured the levels of a variety of factors across a range of occupations at different levels of risk, and investigated the associations with the incidence (or prevalence) of MSDs for the populations concerned [7,8]. Subsequently, measures to limit exposures have been proposed for those factors that increase risk [9–12].

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The accurate measurement of workers' exposure to the factors that may contribute to the development of WMSDs has been of vital importance to both epidemiologists and ergonomists conducting research studies. There has also been parallel interest from ergonomics practitioners, occupational health physicians, employers, employee representatives and regulating authorities in measuring exposure to known risk factors as the basis for programmes of risk prevention and reduction. It is now accepted that these programmes should be founded upon ergonomics principles and should incorporate the holistic assessment of all elements of the work system so that optimal solutions can be achieved. This range of generic issues should be considered, such as task design, worker/equipment interface, individual variation (including motivation), training needs, work organization and legal requirements [13].

Methods have been developed for assessing exposure to risk factors for MSDs [1,14], most for assessment of the upper regions of the body such as the back, neck, shoulder, arms and the wrists. The aim of this review is to

provide an overview of the range of methods that have been developed, to consider their respective merits and to discuss the issues that should be considered when selecting and using an assessment instrument. Emphasis will be given to aspects that are of particular importance to occupational safety and health practitioners who are responsible for programmes of risk prevention and reduction.

Methods for exposure measurement

It has been proposed [2] that mechanical exposure during physical work should be described by three main dimensions: level—intensity of the force, repetitiveness—the frequency of shifts between force levels and duration—the time the physical activity is performed. Any attempt to quantify exposure should therefore include all the three dimensions for a worker being assessed. Data should also be recorded for the other important exposure factors, such as postural variation, rate of movement and vibration, as well as the measurement of psychosocial and organizational factors that may be present in the workplace concerned.

Review methodology

Electronic databases were searched by 'Ergonomics Abstracts' and OSH-ROM (a major collection of bibliographic databases pertaining to occupational health and safety, and environmental medicine [CISDOC, HSELINE, MHIDAS, NIOSHTIC, RILOSH, OEM subset of MEDLINE]) using the keyword terms 'ergonomics', 'work-related musculoskeletal disorders', 'exposure', 'posture', 'assessment' and 'questionnaire' and combinations of these terms. Many significant publications were found about specific exposure assessment techniques. The findings from recent conference and workshop discussions on exposure assessment were used [15,16].

Exposure assessment techniques

A wide range of methods has been identified and categorized under the three headings that have conventionally been used by earlier reviewers [1,2] and they are listed below in order of increasing precision of the data gathered from and invasiveness to the worker(s) being assessed:

- self-reports,
- observational methods and
- direct measurements.

Self-reports

Self-reports from workers can be used to collect data on workplace exposure to both physical and psychosocial factors by using methods that include worker diaries, interviews and questionnaires. Generally, data collection has been by written records, but more recent innovations include the self-evaluation of video films of work tasks [17] or the use of web-based questionnaires [18]. Some examples of studies using self-report are shown in Table 1. Related information on demographic variables, reported symptoms, including pain and postural discomfort, and/or levels of subjective exertion may be gathered as well.

These methods have the apparent advantages of being straightforward to use, applicable to a wide range of working situations and appropriate for surveying large numbers of subjects at comparatively low cost. Estimations of exposure for extended periods can be determined and for longer duration than may be realistically expected by making observations at the workplace. Large samples sizes are normally required to ensure that the data gathered are representative of the occupational groups being investigated. The subsequent analysis costs can be high and appropriate skills are necessary to interpret the findings accurately.

A major problem with these methods is that worker perceptions of exposure have been found to be imprecise and unreliable. For example, having severe low back or neck pain was found to increase the probability of workers reporting higher durations or frequencies of physical load in comparison with those workers from the same occupational groups who were pain free [19,25], although no support for this effect was found by other investigators [26]. Further, difficulties with self-reports may arise from varying levels of worker literacy, comprehension or question interpretation [27].

Although quantification of the absolute level of exposure is doubtful using these methods [20], occupational groups at comparatively higher risk can be identified for more detailed analysis using other methods [28]. Their levels of reliability and validity are reportedly too low for use as the basis for ergonomics intervention [14].

Simpler observational techniques

A number of simpler methods have been developed for systematically recording workplace exposure to be assessed by an observer and recorded on pro-forma sheets, as shown in Table 2.

The number of exposure factors assessed by different techniques varies. Some permit only postural assessments of various body segments to be made, but the majority assess several critical physical exposure factors, as shown in Table 3. Some of the above-mentioned techniques

Table 1. Examples of studies using self-reports

Reference	Study population	Main features	Function
[19]	Forestry workers ($n = 2756$)	Ordinal scales for physical workload and musculoskeletal symptoms	Exposure assessment and prevalence of musculoskeletal symptoms
[20]	Retail, postal, airport, nursing and manufacturing workers ($n = 123$)	Visual analogue scales and categorical data	Estimates of the magnitude, frequency and duration of work physical demands
[21]	Tree-nursery workers ($n = 71$)	Visual analogue scales and categorical data	Assessment of risk factors
[22]	General population ($n = 14\ 556$)	Impact scales for handling work and Nordic Questionnaire for MSD symptoms	Mechanical exposure estimates for the shoulder neck region
[17]	Automotive workers ($n = 7$)	VIDAR—operator self evaluation from video films of the work sequence	Worker ratings of load and estimations of related pain and discomfort
[23]	Range of occupations including nurses, metal and shipyard workers ($n = 1575$)	DMQ—categorical data for work load and hazardous working conditions (to provide seven indices)	Analysis of musculoskeletal workload and working conditions to identify higher risk groups
[24]	Health care, shop assistants, bank employees and secretaries ($n = 93$)	Visual analogue scales, categorical data and interview	Assessment of psychosocial risk factors for shoulder and neck pain
[18]	Office workers ($n = 92$)	Reporting of ergonomic exposures using web-based recording method	Index of ergonomic exposures, pain, job stress and functional limitations

[35,36] gather subjective data from workers systematically as part of the assessment of physical or psychosocial demands.

These methods have the advantages of being inexpensive and practical for use in a wide range of workplaces where using other methods of observing workers would be difficult because of the disruption caused. They may be subject to intra- and inter-observer variability when choosing between different categories of exposure level, and are more suited to the assessment of static (posture held) or repetitive (simple pattern) jobs [1].

A number of methods enable overall indices or scores for combinations of exposure factors to be determined [31,32,35,36,38,43] with the aim of prescribing acceptable exposure limits for workers, or at least establishing priorities for intervention across a range of tasks. The epidemiological data upon which these scoring systems are based is limited particularly with respect to how different factors should be weighted, or interactions between factors should be quantified. The scoring systems are therefore largely hypothetical.

Advanced observational techniques

A range of video-based observational techniques has been developed for the assessment of postural variation for highly dynamic activities; some examples are given in Table 4.

Each of these methods record data either on videotape or by computer that are subsequently analysed objectively using dedicated software. The worker's postural variations are recorded in real time for a representative work period, and several joint segments may be analysed simultaneously. A number of dimensions may be determined, such as distance of movement, angular changes, velocities and accelerations.

The analysis may include the use of biomechanical models that represent the human body as a set of articulated links in a kinetic chain and use anthropometric, postural and hand-load data to calculate intersegmental moments and forces [52]. These range in complexity from two-dimensional static models to three-dimensional dynamic models.

The costs of the above-mentioned systems can be substantial, and they require extensive technical support from highly trained staff for effective operation. They can be time consuming to use in practice and have been found more suitable for use in recording and analysing simulated tasks, rather than for conducting practical assessments in the workplace.

Direct methods

A wide range of methods has been developed that rely on sensors that are attached directly to the subject for the measurement of exposure variables at work. Examples of the types that have been developed are shown in Table 5. These methods range from simple, hand-held devices for the measurement of the range of joint motion to electronic goniometers that provide continuous recordings of the movement across joints during the performance of a task. Lightweight devices have been developed for application directly across articulating joints for the measurement of finger and wrist angles and forearm rotation [58] together with corresponding

Table 2. Examples of simpler observational methods

Reference	Technique	Main features	Function
[29]	OWAS	Time sampling for body postures and force	Whole body posture recording and analysis
[30]	Checklist	Assessment of legs, trunk and neck for repetitive task	Checklist for evaluating risk factors
[31]	RULA	Categorization of body postures and force, with action levels for assessment	Upper body and limb assessment
[32]	NIOSH Lifting Equation	Measurement of posture related to biomechanical load for manual handling	Identification of risk factors and assessment
[33]	PLIBEL	Checklist with questions for different body regions	Identification of risk factors
[34]	The Strain Index	Combined index of six exposure factors for work tasks	Assessment of risk for distal upper extremity disorders
[35]	OCRA	Measures for body posture and force for repetitive tasks	Integrated assessment scores for various types of jobs
[36]	QEC	Exposure levels for main body regions with worker responses, and scores to guide intervention	Assessment of exposure of upper body and limb for static and dynamic tasks
[37]	Manual Handling Guidance, L23	Checklists for task, equipment, environment and individual risk factors	Checklist for identifying risk factors for manual handling
[38]	REBA	Categorization of body postures and force, with action levels for assessment	Entire body assessment for dynamic tasks
[39]	FIOH Risk Factor Checklist	Questions on physical load and posture for repetitive tasks	Assessment of upper extremities
[40]	ACGIH TLVs	Threshold limit values for hand activity and lifting work	Exposure assessment manual work
[41]	LUBA	Classification based on joint angular deviation from neutral and perceived discomfort	Assessment of postural loading on the upper body and limbs
[42]	Upper Limb Disorder Guidance, HSG60,	Checklist for ULD hazards in the workplace	Assessments of ULD risk factors
[43]	MAC	Flow charts to assess main risk factors to guide prioritization and intervention	Assessment of risk factors for individual and team manual handling tasks

systems for computerized data analysis [57]. In addition, systems have been developed for the simultaneous recording of multiple wrist, hand and finger movements together with grip pressure directly online to a laptop computer [63]. The Lumbar Motion Monitor [56] is an electronic exoskeleton applied to the torso that records continuous data for three-dimensional components of trunk position, velocity and acceleration for subsequent analysis by computer. In addition, tri-axial accelerometers have been developed that in combination with appropriate software, are suitable for the assessment of body postures and movements during whole-day ambulatory monitoring of occupational work [59,60]. Such devices can be used to determine the time that individuals spend in different postures during the course of their working day.

Techniques have been developed for recording body posture that rely on the attachment of optical, sonic or electromagnetic markers to specific anatomic points on the worker and are used with corresponding scanning units to track the position and angular movement of different body segments [14]. The three-dimensional coordinates of all body markers can be recorded in real time using dedicated computing systems. These systems appear to be more suited to the investigation of task simulations, as opposed to investigations at industrial locations.

Another direct method is the synchronous recording and computerized analysis of myoelectrical activity (EMG). This can be used to estimate muscle tension [61,64] although the relationship may be non-linear in many circumstances, therefore a careful interpretation is required. It may also be used to evaluate local muscle fatigue that relies on changes in the spectral characteristics of the myoelectric signal, although again interpretation may be difficult [65].

Table 3. Exposure factors assessed by different methods

Reference	Technique	Posture	Load/ force	Movement frequency	Duration	Recovery	Vibration	Others[a]
[29]	OWAS	×	×					
[30]	Checklist	×						
[31]	RULA	×	×	×				
[32]	NIOSH Lifting Equation	×	×	×	×	×		×
[33]	PLIBEL	×	×					×
[34]	The Strain Index	×	×	×	×			×
[35]	OCRA	×	×	×	×	×	×	×
[36]	QEC	×	×	×	×		×	×
[37]	Manual Handling Guidance,	×	×	×	×	×		×
[38]	REBA	×	×	×				×
[39]	FIOH Risk Factor Checklist	×	×	×	×			×
[40]	ACGIH TLVs	×	×	×	×			
[41]	LUBA	×						
[42]	Upper Limb Disorder Guidance, HSG60	×	×	×	×		×	×
[43]	MAC	×	×	×				×

[a]These include, mechanical compression, glove use, environmental conditions, equipment, load coupling, team work, visual demands, psychosocial and individual factors.

Direct measurement systems can provide large quantities of highly accurate data on a range of exposure variables. The attachment of sensors directly to the subject may result in discomfort and possibly some modification in work behaviour. The enhanced data generation capacity of many of these systems may be considered impractical by many practitioners because of the time required for the analysis and interpretation of the data. Direct measurement systems require considerable initial investment to purchase the equipment, as well as the resources necessary to cover the costs of maintenance and the employment of highly trained and skilled technical staff to ensure their effective operation [14].

Discussion

It is evident that various methods are available for the assessment of exposure to workplace risk factors for

Table 4. Examples of advanced observational methods

Reference	Technique	Main features	Function
[44]	Video analysis	Time sampling of video films and computerized data acquisition for both posture and force	Posture assessment of hand/finger
[45]	ROTA	Computerized real time or time sampling recording and analysis of activity and posture	Assessment of dynamic and static tasks
[46]	TRAC	Computerized time sampling recording and analysis of activity and posture	Assessment of dynamic and static tasks
[47]	HARBO	Computerized real time recording of activity and posture	Long duration observation of various types of jobs
[48]	PEO	Computerized real time recording of posture and activity	Various tasks performed during period of job
[49]	Video analysis	Analogue data recordings synchronized with video images	Various manual tasks
[50]	PATH	Computerized work sampling of posture and activity	Non-repetitive work
[51]	SIMI Motion	Video-based analysis of three dimensional movement	Assessment of dynamic movement of upper body and limbs
[52]	Biomechanical models	Linked segmental representation of the human body	Estimation of internal exposures during task performance
[53]	Video analysis	Tri-axial video-based observational method for quantification of exposure	Computerized estimation of repetitiveness, body postures, force and velocity
[54]	Video analysis	Video-based recording of upper extremity posture	Assessment of dynamic and static tasks
[55]	Video analysis	Digital video capture and analysis of body postures	Measurement of trunk angles and angular velocities

Table 5. Examples of direct methods

Reference	Technique	Main features	Function
[56]	LMM	Triaxial electronic goniometer	Assessment of back posture and motion
[57,58]	Electronic goniometry	Single or dual plane electronic goniometers and torsiometers to record joint posture	Measurement of angular displacement of upper extremity postures
[59,60]	Inclinometers	Tri-axial accelerometers that record movement in two degrees of freedom with reference to the line of gravity	Measurement of postures and movement of the head, back and upper limbs
[14]	Body posture scanning systems	Optical, sonic or electromagnetic registration of markers on body segments	Measurements of displacements, velocities and accelerations of a body segment
[61]	EMG	Recording of myoelectrical activity from exercising muscles	Estimation of variation in muscle tension and force application
[62]	Force measurement	Computer mouse with sensors recording forces applied to side and button	Determination of finger force exposures
[63]	CyberGlove	Lightweight glove incorporating 22 motion sensors and Uniforce pressure sensors	Measurement of wrist, hand and finger motion with superimposed grip pressure

WMSDs. The choice of method(s) will depend upon the nature of the investigation and the purpose(s) for which the data will be used; these will determine the level of accuracy and precision that is required. A well-constructed hypothesis regarding the way that specific workplace factors contribute to the overall workplace exposure is necessary, as this will ensure that appropriate techniques are employed to gather relevant data for the investigation concerned. The core considerations for the design of a measurement strategy [66] are summarized in Table 6.

The technique(s) selected should be appropriate to the requirements of the measurement strategy that is developed. Some methods are suitable for use only by highly skilled investigators and require extensive use of resources. Other techniques that enable more general, observation-based assessments to be made are more suited to the needs of occupational safety and health practitioners or those from related professions, who have limited time and resources at their disposal for making assessments. These practitioners are often faced with the challenge of preventing or reducing the number of MSDs in the workplace and need a basis for establishing priorities for intervention.

Assessing exposure to risk factors for WMSDs is an essential stage in the management and prevention of WMSDs, when it may form part of an overall-risk-assessment programme. Ideally, practitioners need techniques to assess exposure that are easy and quick to use, that are sufficiently flexible to be applied to a range of jobs, and that are comprehensive and reliable for a range of risk factors. A number of methods have been developed to meet at least some of these requirements (see Table 2). Practitioners would be helped, therefore, by the development of a systematic approach to compare the advantages and disadvantages of different methods that would allow an informed choice to be made about which techniques to use in which situations. Workshops and discussions with practitioners [16] have identified several issues that need to be addressed.

What level of resource is required?

The costs of acquisition, training and the time required to undertake assessments and analyse the data will vary for different methods. Practitioners may have very limited time to carry out assessments, therefore the assessment method should be straightforward and quick to use. Many of the methods listed in Table 2 are freely available from developers or associated sources. Users will still need to become conversant with their application and gain confidence in their use. The assessment method

Table 6. Basic considerations in establishing a measurement strategy for work-related musculoskeletal disorders [66]

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

chosen should be cost effective for the organization concerned and commensurate with the levels of skill of those working there.

How comprehensive is the exposure assessment method?

The range of factors considered by different methods varies widely; Table 3 provides a comparison of the factors assessed by the simpler observational techniques that are more likely to be used by practitioners. Generally, more emphasis has been given to enabling physical factors to be assessed. Some methods allow for the assessment of the whole body including lower limbs [29, 38]. Psychosocial and work organizational factors are addressed by very few methods, and only in a limited way.

There is a need to widen the range of factors that are currently included, and to consider the interactions between those factors that are currently assessed. In line with the ergonomics approach to making interventions, the assessment methods that focus principally on physical factors in the workplace should be complemented by appropriate ergonomic techniques that address the wider organizational issues so that optimal solutions can be found.

How much assistance does the method give with making workplace interventions?

Practitioners need to establish priorities for workplace interventions based on the assessments they have carried out. Importantly, they also need to convince managers to allocate appropriate levels of resources to make improvements. Scoring systems and associated evaluation criteria have been developed for several of the assessment methods [31,35,36] that enable the levels of exposure for the relevant factors to be combined to give scores for specific body areas or a combined total calculated for the task concerned. Scores may then be compared, actions proposed dependent upon the perceived need and estimates made of the level of improvement afforded by making the change. In the absence of anything that can be shown to have greater validity, the current scoring systems are popular with practitioners and managers as they assist communication and decision-making.

How reliable and valid are exposure assessment methods?

Exposure assessment in the workplace may be difficult because of the effects of the surroundings on the accuracy of data collection. Direct measurement techniques can provide more reliable data than those based on observations or subjective judgements.

A major challenge is posed in validating exposure assessment techniques. Ideally, this should be done by documenting the levels of exposure for the full range of factors assessed using the technique(s), then subsequently recording the health outcome measures across a range of occupations exposed for a sufficient period. An alternative strategy for establishing validity that has been utilized is to compare the results of different methods, e.g. observation and direct measurement, to determine the level of agreement between the two [19,36,67].

How many workers can or should be observed to ensure that the assessment is representative of the exposure profile for the population under investigation?

Much effort has been devoted to the design of data collection strategies for establishing exposure profiles in epidemiological investigations [68]. This is especially difficult for jobs where there is considerable temporal variation in the exposure factor of interest. An effective data-collection strategy should enable an estimate of a group mean exposure for a job to be established with sufficient levels of accuracy (small bias) and precision (small random error), and with the minimum possible investment of resources [69]. The use of 'bootstrap' procedures have been proposed in epidemiological studies to investigate the precision of determinations of the mean exposure for the total group of workers concerned [70]. It was discovered that monitoring between 15 and 25 workers from a group was probably the minimum number for an adequate estimate of the group average exposure to trunk flexion to be made. It is unlikely that occupational safety and health practitioners will have the resources to monitor these numbers of workers in each occupational group they are called upon to survey. It is questionable therefore if the tasks that are assessed are representative of those performed by other workers in the job and throughout the organization, in different locations and at different times of year. This issue is of major importance, and has not been addressed by the developers of assessment techniques designed for use by practitioners.

How transferable is the method between different situations?

It is useful to have a common procedure in use across an organization when establishing priorities for intervention. The requirement for an assessment technique to be sufficiently flexible to be applied to a range of jobs was one of several key factors identified by practitioners in a survey undertaken as part of the development of the Quick Exposure Check [36]. The more comprehensive the technique (see Table 3), the more likely it will be that it will cover the range of different risk factors found at different workplaces across an organization.

Nevertheless, no technique has so far been found suitable for all applications.

Conclusions

The assessment of exposure to risk factors for MSDs in the workplace is a complex and problematical area. A wide range of assessment methods has been developed that fall within three main categories that have been described.

A major challenge is posed in selecting the appropriate method or combination of methods from this range that have been developed. The more general, observation-based assessments appear to be best matched to the needs of occupational safety and health practitioners (or those from related professions) who have limited time and resources at their disposal and need a basis for establishing priorities for intervention. Even so, this user group would benefit from the development of a decision aid that would allow them to make an informed choice about which techniques are most suited to which practical situations they are called upon to assess.

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