

the observation increases because several classes of postures are incorporated, the consistency between observers decreases (39). This decrease confirms the results of van der Beek and Fransson-Hall. As pointed out by Keyserling, differences between observers, when recording the posture of a certain body region in several classes, are due to disagreements concerning the boundaries of adjacent postures. Among the body regions, neck posture appears to be the most difficult to assess accurately, even with only three classes (Fransson-Hall et al, unpublished manuscript).

Intraobserver reliability appears to be relatively high, and higher than interobserver reliability, even with several months separating repeated observations of a video recording (39, 60, Fransson-Hall et al, unpublished manuscript).

Internal validity

The internal validity of observations (ie, the extent of agreement between observations and other, more accurate measurements) have only been tested for a few methods. Keyserling compared results obtained in a simulated real-time observation with a frame-by-frame video analysis and obtained a high degree of agreement for the proportion of time spent with the back in a neutral position and in severe flexion, the shoulders in a neutral position and in mild and severe flexion or abduction (39). Observations of back and left-right shoulders were made in three separate sessions. Time spent with the back twisted or bent was overestimated, probably due to the difficulty of translating a two-dimensional video observation into three dimensions. Burdorf validated OWAS observations of trunk flexion (>20 degrees) using inclinometer recordings and found a significant correlation between the two methods for the time spent in forward flexion, during both sedentary and dynamic work (61). However, large differences between the two methods were obtained for individual subjects. Especially, the proportion of time in forward flexion of the back was vastly overestimated by sedentary workers. In a recent study, Leskinen et al (unpublished manuscript) validated the PEO method using video recordings and an optoelectronic recording system (sel-spot). Measured trunk flexions between 50 and 60 degrees were systematically coded as exceeding 60 degrees, but there was good agreement between the proportion of time observed as exceeding 60 degrees, but recorded as exceeding 50 degrees. The requirement for recording trunk rotation (ie, >45 degrees) proved unrealistic, as it did not occur in the realistic range of the tasks studied. Observations of neck postures (>20 degrees) were unreliable with regard to both duration and frequency. The authors concluded that there was a high degree of agreement between measured and observed data for durations of sustained postures (except neck flexion) and long-lasting repetitive activities (typing).

The frequency of clearly distinguishable actions like lifts could also be recorded accurately. Even reducing the number of exposure types by half did not substantially improve the agreement between the observations and measurements, and this result was interpreted as indicating that demands on the data processing capacity of the observer during simultaneous measurements of several factors were too high.

For detailed observations of postures, it appears that the ability of the observer to distinguish between adjacent angular sectors (eg, more or less than 60 degrees of flexion) is the crucial problem. In an experimental study, Ericson et al (62) compared the observations obtained by experienced ergonomists, direct observations, and observations from video recordings to those obtained by a video position analyzer. The observations were made in the sagittal plane. Observations of the trunk, neck, and upper-arm inclinations could be made with an accuracy of about five degrees during static conditions and with somewhat higher accuracy during dynamic conditions, and direct observations did not differ from those obtained from video recordings. The accuracy was somewhat better close to horizontal and vertical than in the intermediate range. Similar results were obtained by van der Beek et al (47) when they compared observations from a photograph with optoelectronic recordings. Obviously these results were obtained under optimal conditions, and in a more complex environment accuracy is likely to be lower. Nevertheless, systematically trained observers should be able to observe angular sectors and thus achieve more than a mere dichotomous observation of posture.

External validity and applicability

For the purpose of this review, external validity is defined as the ability of an observation method to identify physical exposures associated with an increased risk of musculoskeletal disorders. Prerequisites for high external validity are (i) a correct underlying hypothesis (ie, a relationship between certain physical exposures and musculoskeletal disorders exists) and (ii) an exposure observation method designed (operationalized) to permit exposures to be assessed with sufficient accuracy.

Even though the underlying hypothesis may be correct, the latency time between exposure and the overt symptom or disease may be too long to permit an association to be demonstrated in a cross-sectional study. This however is a problem inherent for any method used to assess current physical exposure, be it by direct measurement, observation, or questionnaire.

Table 2 summarizes some epidemiologic studies in which observation methods have been used to quantify exposure. The table contains two studies in which neck flexion, shoulder elevation, and abduction are associated with shoulder-neck disorders. In four studies repetitiveness, force, and speed of hand-

arm movements have been associated with forearm-wrist-hand disorders, and in two studies a bent or twisted back has been associated with low-back disorders. One study has demonstrated a relationship between the duration of standing and back, lower-limb and foot symptoms, and another has shown an association between accidents and back posture or lifting.

Considering that table 1 contains 19 observation methods for postural assessment, to which can be added NIOSH's procedure for evaluating lifting and the method of Silverstein et al for repetitive work, the application of observation methods for musculoskeletal epidemiology is certainly very sparse. Their application for ergonomic purposes is more common, but even then each group of researchers appears to favor the development of a new method rather than the use of one developed by others. As a matter of fact, only the OWAS method has been applied widely for epidemiologic and ergonomic purposes. It may be that most methods have been documented only in the last six or seven years and that more applications can be expected as the importance of exposure assessment becomes more evident. Even though table 2 demonstrates that observation methods can be used to study the relationship between physical exposures and musculoskeletal disorders, more studies need to be performed before the external validity of observation methods has been proved.

Operationalization

The design of scales, the number of exposure factors recorded simultaneously, the mode of observation (film-video or direct), the mode of time monitoring (continuous or time sampling), and the recording system (pencil and paper or computer) all constitute aspects of the operationalization of an observation method. All of these factors profoundly influence the reliability and validity of the method.

Pencil-and-paper or computerized registration?

Most observation methods of recent years are computerized (ie, the internal clock of the computer is used for keeping time and automatically recording the durations), and each exposure factor is assigned one key or a combination of keys on the computer keyboard. The recordings can either be performed directly at the workplace, by use of a portable or hand-held computer, or from video recordings subsequently analyzed in the laboratory. The most widely used observation method, OWAS, has now also been computerized (33). The gains of computerization are twofold. The time needed for recording is reduced, and the entire cognitive capacity of the observer is made available for observation rather than for keeping time. Use of a portable computer has the advantage of enabling direct feedback of detailed information from the screen to the observer. Thereby

errors in registration can be detected immediately. Moreover, for teaching and training purposes this feedback is valuable. A small hand-held computer provides less detailed feedback to the observer but is, on the other hand, easier to carry at the workplace. Experience with the PEO method shows that intra- and interobserver reliability is not negatively affected by the use of hand-held computers versus portable computers, provided the observers are trained (Fransson-Hall et al, unpublished manuscript).

Direct or film-video registration? The advantage of direct observation is that postures are likely to be recorded more accurately, since human vision is three-dimensional whereas a film-video recording is reduced to a two-dimensional image. In an experimental study, Ericson et al (62) did not find any differences between observations registered directly and via video recordings, provided the observations were performed in the sagittal plane. Paul & Douwes (64) compared a two-dimensional assessment of postures from photographs with a three-dimensional evaluation using an optoelectronic system. Their results indicate that two-dimensional recordings give sufficient accuracy, as long as some guidelines for the reduction of perspective errors are followed. Keyserling noted however that the observers misjudged the proportion of time spent with a twisted back when the assessment was done from a video recording, while a direct assessment was more accurate (39). Stetson et al (45), comparing direct observations with a video analysis of hand and wrist postures and grip types, concluded that direct observations were more accurate. In addition, it is easier to move around a workplace and secure optimal viewing angles when the observer carries only a hand-held computer rather than a video camera, which requires additional attention and adjustments. On the other hand, a video recording can be analyzed repeatedly, and this ability is necessary when tasks done at a high work pace are being observed, and also when many exposure factors are recorded simultaneously. Therefore, direct registration at the workplace can only be recommended when only a few variables are being assessed or when the work pace is slow.

Real time or time sampling? A certain exposure can be registered when a new situation arises, for example, when a posture changes or a manual handling activity is performed (19, 39, 44, 45, 47, 65, Fransson-Hall et al, unpublished manuscript). This is an event-driven procedure, in real time or simulated real time, and it enables the computer program to assess the sequence, duration, and frequency of each event and each separate exposure factor. Alternatively, registrations can be performed at certain intervals (which may be regular or irregular, depending on the regularity of the job). Such a time-sampling procedure, with sampling intervals of 10–30 s has been

Table 2. Associations between observed physical exposures and musculoskeletal disorders in some epidemiologic studies. (OR = odds ratio)

Author	Type of study	Occupational group	Exposure assessment
Feuerstein & Fitzgerald 1992 (19)	Case-referent	Sign language interpreters, 16 with and 13 without pain	Observation of standard interpretation task
Fransson-Hall et al (unpublished manuscript)	Cross-sectional	Automobile assembly-line workers, 11 from low and 9 from high-symptom divisions	Hand PEO, see table 1; observation of representative work tasks
Jonsson et al 1988 (21)	One- and two-year follow-up	69 electronics assembly workers	VIRA at start of study; see table 1.
Karhu et al 1977 (30) Burdorf 1992 (69)	Cross-sectional	120 male workers (4 occupational groups) versus 52 referents	Random selection of two or three workers per job; observation of back, legs and lifting by OWAS, interval 20s, all activities recorded
Keyserling 1986 (39) Punnett et al 1991 (63)	Case-referent	Automobile assembly workers: 95 cases reporting back pain, 124 referents without back pain	See table 1, some "proxy" workers also analyzed when observation of case was not possible
Kilbom et al 1986 (44)	Cross-sectional	96 female electronics assembly workers	VIRA, see table 1, observation of typical work tasks, also work history and productivity
Ryan 1989 (42)	Cross-sectional	513 supermarket workers	See table 1; sampling for 30 min, one to two workers per store observed
Silverstein et al 1986 (52)	Cross-sectional	574 industrial workers representing 34 jobs, >20 workers per job	Observation of individual jobs, video and electromyography of typical jobs; high repetitivity cycle time <30 s, high force >4 kg, low force <1 kg
Silverstein et al 1987 (53)	Cross-sectional	652 industrial workers representing 39 jobs, >20 workers per job	See above
Wickström et al 1985 (18)	Cross-sectional	Concrete reinforcement work and house painting	Observation of all work tasks for 272 h at eight work sites; two observers, see table 1

used, for example, in OWAS (30) and posture targeting (24) and by Baty et al (46), Ryan (42), Wickström et al (18), and van der Beek et al (48). Provided sampling intervals are chosen appropriately with regard to the pace of the job, time sampling gives a reasonable approximation of the duration and frequency of each exposure factor. The ROTA method developed by Ridd et al provides the possibility of using either real time or time sampling (37).

Real-time procedures provide more information but put very large cognitive demands on the observer

in fast jobs. The solution may be to use repeated observations of a video recording in slow motion or two observers instead of one, as done by Wickström et al (18) and proposed by van der Beek et al (48). So far the advantage of real-time observations over time sampling has not been proved conclusively. Although information gathered on the duration of each exposure event is likely to be of large potential value for understanding the etiology of musculoskeletal disorders, it has not been used in epidemiologic studies so far.

Responses	Control	Main results	Comments
Current arm pain during interpretation	Job seniority, age	Fewer rest breaks, more frequent hand and wrist deviations and more rapid hand and finger movements among symptomatic subjects	·
7-d and 12-month prevalence of symptoms, forearm-hand	·	Duration and frequency of operations differed between high- and low-symptom division and between right and left	·
Deterioration or improvement of neck-upper limb disorders; Remaining healthy for two years	·	Percentage of work cycle in shoulder elevation negatively associated with remaining healthy; work cycle time negatively associated with deterioration	Satisfaction with work tasks positively associated with remaining healthy
Twelve-month prevalence of back disorders by Nordic questionnaire	Previous back pain, age	Study group versus reference group: OR 2.80, log regression: time spent with back bent or twisted and whole-body vibration (two levels) both significant for back disorders	Previous physically heavy job; height, weight and heavy lifting not associated with back disorders
Filed reports of back disorders	Gender, age, job seniority, leisure-time habits, medical history	OR ~10 for back in mild, severe flexion and twist or lateral bend, OR ~5 for proxy subjects; high duration of exposure increased risk estimate	·
Neck and upper extremity disorders in four degrees of severity	Previous neck-shoulder sick leave	Multiple regression analysis: time in neck flexion, arm abduction related to neck shoulder disorders	Productivity associated with disorder
Twelve-month prevalence of disorders by Nordic questionnaire	·	Strong association for percentage of time standing and disorders of back, lower limb and foot	·
Cumulative trauma disorders by questionnaire and clinical examination	Previous cumulative trauma disorders	OR for high force—high repetitiveness 29, high force—low repetitiveness 5, low force—high repetitiveness 3, all versus low force—low repetitiveness	Force stronger risk factor than repetitiveness
Carpal tunnel syndrome by questionnaire and clinical examination	Previous carpal tunnel syndrome	OR for high force—high repetitiveness 16, high force—low repetitiveness 2, low force—high repetitiveness 3, all versus low force—low repetitiveness	Repetitiveness stronger risk factor than force; slight age (not significant), no gender effects; vibration likely risk factor
Minor accidents in study group, reported accidents (national statistics)	·	Concrete workers more back flexion, static postures, more lifting; also more minor and reported accidents	Exposure and responses not recorded on same group

Number of exposure factors. Most observation methods use a number of main exposure categories, for example, posture of trunk and arms, manual handling, repetitive work, tasks. In each of these main categories several subcategories can be used, for example, posture of trunk in three subcategories of flexion and two subcategories of side-bending or twisting. The methods presented in table 1 contain up to 23 different subcategories of exposures, to be observed simultaneously. Although the tests of reliability and internal validity performed so far are in-

sufficient in many ways (see the preceding discussion), it can be concluded that a large number of observed factors reduce the precision of observations. van der Beek et al (48), using a time-sampling modification of the ROTA method with 23 exposure subcategories, evaluated the interobserver reliability from video recordings. Their conclusion was that two observers are needed to perform all required registrations. One observer should pay attention only to posture, while the second observes tasks, manual handling, workplace characteristics, and used aids.

Leskinen et al (unpublished manuscript) studied the validity of the PEO method, which uses real-time observations, by comparing optoelectronic registrations with direct observations. Their conclusion was that, even when the number of subcategories is halved (from 21 to 10), the agreement between methods does not improve substantially. These results indicate that a maximum of about 10 simultaneous subcategories can be observed simultaneously. In high-paced and dynamic jobs the number of categories will probably have to be substantially reduced; alternatively the analysis has to be performed repeatedly from video recordings. Whenever a simultaneous observation of several exposure categories is made, a priority list should be followed so that assessment of the most important categories is guaranteed.

Design of scales. The majority of categories or subcategories are dichotomous (ie, an exposure is registered only when it occurs, eg, sit, push, lift, neck flexion, back flexion, repetitive work). More detail can be obtained by subdividing into classes using interval scales (eg, back neutral, bent 20–45 degrees, bent >45 degrees, or lifting 1–5, 6–15, 16–45 and >45 kg). Unfortunately the class limits vary considerably between methods. Continuous scales have been tried in the posture targeting method (24) and by Chang et al (43), but they are extremely time consuming.

The reliability of dichotomous, gross body posture registrations like sit, walk, kneel, and squat is usually reported to be high, whereas postural assessments are sometimes relatively unreliable (eg, neck flexion).

Classifying back posture into several categories must be considered biologically relevant, as the load on the back extensor muscles and the compressive forces in the spine are highly dependent on the flexion angle. The choice of a dichotomous or interval scale with up to three classes does not, however, appear to influence reliability. Burdorf & Laan (66) used the OWAS back-posture categories and defined bent back as flexion exceeding 20 degrees, without using additional classes of flexion. Yet large errors, usually excess classification of bent back, were obtained by the observers. When Leskinen et al (unpublished manuscript) validated the PEO method (which classifies back flexion into the three categories of straight, 20–60 degrees and >60 degrees), they obtained errors of about 10 degrees, also with a tendency for observers to overestimate the angle of flexion. Under optimal conditions both Ericson et al (62) and van der Beek et al (48) brought the error of angle estimation down to 5 degrees. Errors of 5–10 degrees must be considered acceptable when back flexion is classified. Twisting and side-bending of the back has been found difficult to classify accurately in most observation methods. Consequently bending and twisting of the back are classified together in

some methods (46, 48). On the basis of the aforementioned results, it is suggested that back flexion be classified into the following three categories: straight (<20 degrees), moderate flexion (20–60 degrees) and pronounced flexion (>60 degrees). More methodological studies are needed to clarify whether better training of observers can improve the precision in the classification of twisting and side-bending.

Another problem is that the exact definition of postural angles is insufficiently reported in many method documentations. This situation indicates that observers have not been sufficiently informed and trained and that the accuracy of angle estimations can be improved by training, as demonstrated by van der Beek et al (48).

In parallel with back posture, arm posture should preferably be subdivided into several classes for biomechanical reasons. Such a subdivision was possible with sufficient reliability in the VIRAM method, which registers in the sagittal or frontal plane, and only records upper arm, neck, and shoulder postures (44). In the general methods no attempts have been made to subdivide arm postures into angular sectors (48, Fransson-Hall et al, unpublished manuscript). Keyserling (classifying in >45- or <45-degree upper-arm elevation) obtained a relatively low reliability for arm postures (39). It is probably easier for the observer merely to classify the hand position (above or below shoulder level), as done in the PEO method, although the estimate of the biomechanical load on the shoulder is less accurate.

Data reduction indices. The OWAS, the RULA, and the ARBAN methods use the original exposure data to develop indices for acceptability (28, 30, 31). These indices are primarily intended as an instrument for priority setting in ergonomic work, and they have not been validated. The lifting index, as calculated in the revised NIOSH procedure, is another such composite measure of exposure (50). Recently Hagberg pointed out that the pattern of exposure (ie, the combination of exposure factors and their distribution over time) may provide better estimates of risk than single exposure variables (67). For such an approach, models based on pathophysiological considerations must be developed. Moreover, the observation (or measurement) of exposure must be performed in real time. This should be an important topic for future research. However, indices or composite measures must never be used in a way that obscures an analysis of the effects of single exposure variables.

Strategy for exposure assessment

Most systematic observations of physical work load have been performed on industrial populations, for whom the variation in exposure, over time and be-

tween workers, has been considered small. Modern trends in industrial rationalization are towards multi-skilling, which implies that exposures are becoming even more varied, both over time and between individuals. In the service branches — hotels, restaurants, cleaning, nursing — as well as among white-collar workers, the variations in exposure have always been marked.

The variability of exposure, both within and between workers in the same occupational group, is a factor that has been neglected in most exposure studies. Intra-worker variability can be expected to vary over the workday, over the week, and between seasons. Inter-worker variability may differ by training and working technique, by age, and by the physical characteristics of the worker. For example, among electronics workers who assembled identical circuit boards, work-cycle times and the distribution of postures over time varied markedly (44). In a study of supermarket checkers, Harber et al (41) showed considerable variation in trunk flexion, both within and between workers. In the vast majority of studies the magnitude of these variations is however unknown.

When different occupational groups are compared, the total variability in exposure assessment is a result of variability within and between workers in the same group and variability between occupational groups. In a comparison between five occupational groups, Burdorf (68) calculated that the between-group variance accounted for 47% of the total variability in trunk flexion and 72% of the variability in trunk rotation. The within-worker and between-worker variance was considerably lower, 29–24% and 16–12%, respectively. The effect of within- and between-worker variability on the bias in risk estimates when occupational groups are compared has been discussed by Burdorf (69). In essence, the overlap in exposure between occupational groups leads to a risk of misclassification that lowers the true risk estimate (odds ratio or prevalence rate ratio).

In occupational groups with a relatively large within-worker variability, a more accurate measure of exposure can be obtained if the observation period is prolonged or repeated exposure assessments are made. Carmines & Zeller (70) and Liu et al (71) have developed statistical methods to assess and minimize intraindividual variability by performing two measurements or more on each worker. The application of these considerations for strategy when postural load on the back is being assessed has been discussed extensively by Burdorf (72). An important practical conclusion is that, when the strategy for exposure assessment is being optimized, the variability of exposure needs to be assessed on the intended study population. The choice between a prolongation of the observation period, versus repeated observations, depends on whether the variation in exposure occurs during the same day or between workdays.

In conclusion, strategy is an important part of exposure assessment (whether by observation or direct

measurement) that so far has received little attention in epidemiologic studies of musculoskeletal disorders. Even though the cited considerations give some guidance, this area is in urgent need of further theoretical and empirical study.

Discussion

This review has revealed several drawbacks of available methods for systematically observing physical exposure. From this review, the following recommendations can be given for improving and further developing observation methods:

1. Postures of the trunk should be classified into several (two to three) categories. A consensus agreement is needed to define these categories, and observers need to be trained carefully in the identification of angular sectors. Whether twisting and side-bending can be assessed separately from flexion needs to be studied with the use of better definitions of these postures.
2. Postures of the shoulder-arm complex appears to be difficult to classify into more than two categories, unless both sagittal and frontal views can be guaranteed.
3. Postures of the neck and head appear difficult to assess with the classifications used so far. Results may improve if different posture classes are used.
4. Gross body postures like sit, stand, kneel can be observed with high accuracy.
5. Repetitive hand-arm work needs to be defined more precisely and methodological development of both observation and direct measurement techniques is needed.
6. Manual handling can be assessed crudely, but it needs complementary measurements for classification into subcategories.
7. The number of simultaneously observed exposure variables should be reduced to less than 10. For observing highly dynamic or high-paced work, the number of variables probably has to be reduced further. If a higher number of variables needs to be observed simultaneously, either two observers or video recordings with repeated viewing need to be used.
8. Computerization of the method is necessary.
9. More emphasis on training observers and more exact definitions of exposure factors will probably improve the reliability and validity of observations.

10. Observations need to be supplemented with an interview of the employee, to ensure that all work tasks are observed, in order that the daily — or weekly — exposure profile can be calculated.

Given that all available observation methods have drawbacks, it is justified to discuss whether systematic observations should be abandoned in favor of direct measurements. However, direct measurements have some serious disadvantages, apart from those already mentioned in the introduction. The attachment of measurement devices and their calibration can introduce sources of systematic error. For some exposure factors, like twisting of the head and trunk and pro/supination of the forearm, no suitable instruments are yet available although methodological development has started. Manual handling in the vertical plane (ie, lifting and carrying) can be assessed by instruments in the workplace (73), but no on-line method is available to record pushing or pulling. Direct measurements of postures give a large amount of data with a high degree of precision; however only a minor part of the data can be used in epidemiologic studies.

In my view the most serious disadvantage of direct measurements is that tasks cannot be registered. Hence the exposure profile cannot be analyzed by task, which is a serious drawback in intervention studies. In addition, measurements are usually more time-consuming than the observation of an equivalent number of variables, if the attachment of devices and their calibration, data analysis, and data reduction are taken into consideration. Until further advances take place in instrumentation, systematic observations of physical exposure have a definite place in epidemiologic studies of musculoskeletal disorders.

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